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(54) **PROSTHETIC JOINT ASSEMBLY AND PROSTHETIC JOINT MEMBER**

(71) Applicant: **BioMedFlex, LLC**, Denver, NC (US)

(72) Inventors: **Franz W. Kellar**, Gastonia, NC (US); **Harold Lloyd Crowder, Jr.**, Concord, NC (US); **Scott M. Duquette**, Clemmons, NC (US)

(73) Assignee: **BioMedFlex, LLC**, Denver, NC (US)

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See application file for complete search history.

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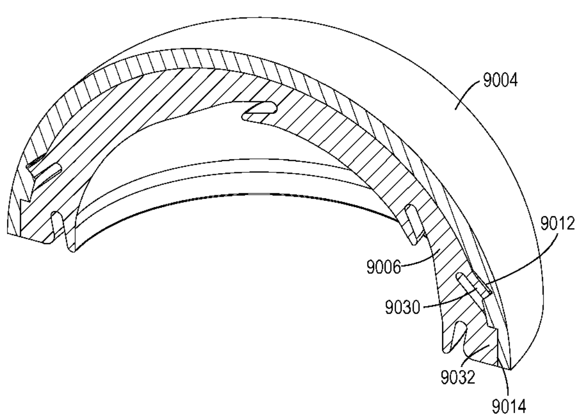
Primary Examiner — Andrew Iwamaye

(74) *Attorney, Agent, or Firm* — Trego, Hines & Ladenheim, PLLC

(57) **ABSTRACT**

A prosthetic joint member includes: a generally concave cup with an outer surface that is bone-implantable, the cup including a first indexing feature; a concave insert disposed inside the cup, the insert comprising a rigid material and including a concave interior defining a nominal surface, the interior including a cantilevered flange defined by an undercut in the insert, the flange defining a wear-resistant first contact surface which protrudes inward relative to the nominal surface, the insert including a second indexing feature. The first and second indexing features engage each other so as to retain the insert in a fixed angular orientation relative to the cup.

18 Claims, 48 Drawing Sheets



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is a continuation of application No. 13/073,963, filed on Mar. 28, 2011, now Pat. No. 8,070,823, which is a continuation-in-part of application No. 12/826,620, filed on Jun. 29, 2010, now Pat. No. 7,914,580, which is a continuation-in-part of application No. 12/714,288, filed on Feb. 26, 2010, now Pat. No. 7,905,919, which is a continuation-in-part of application No. 11/936,601, filed on Nov. 7, 2007, now Pat. No. 9,005,306.

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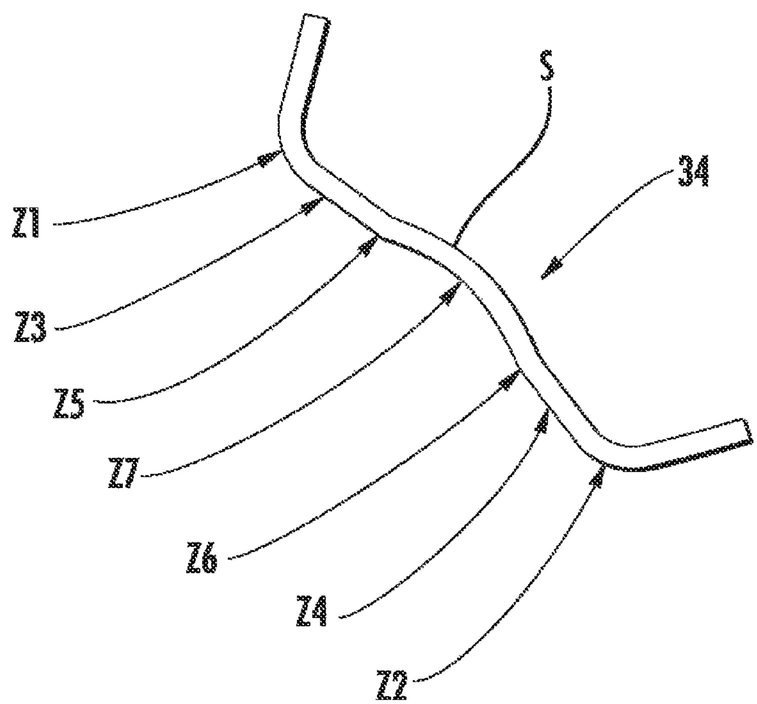
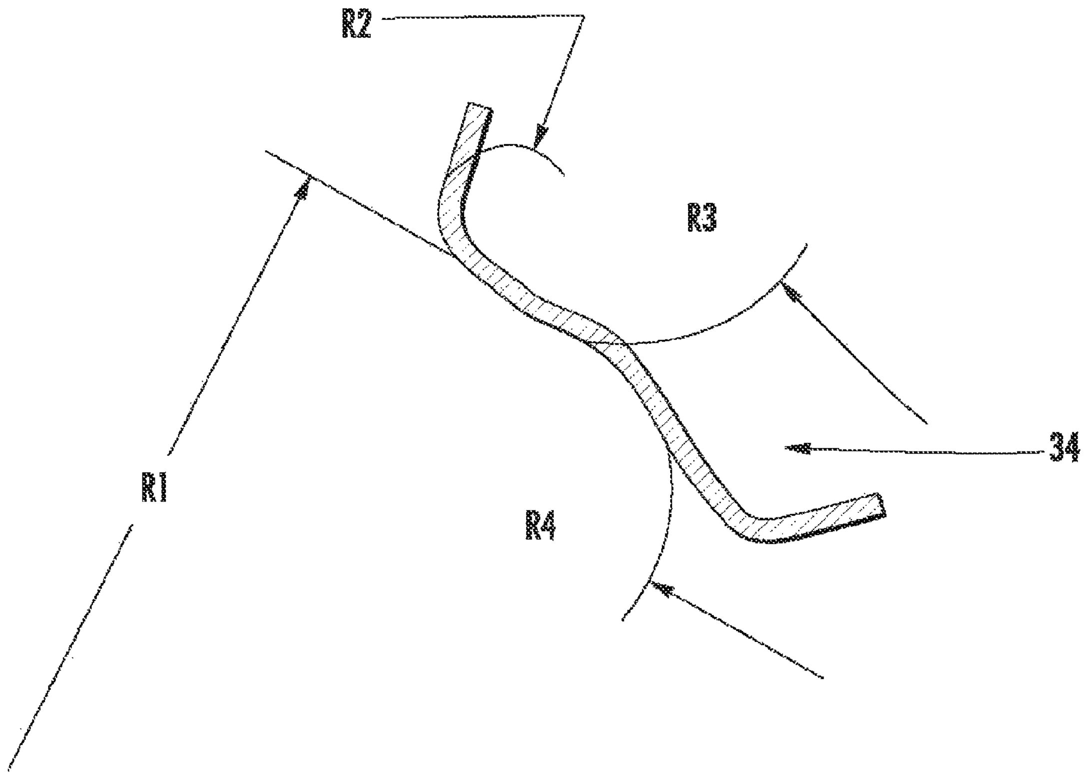


FIG. 1



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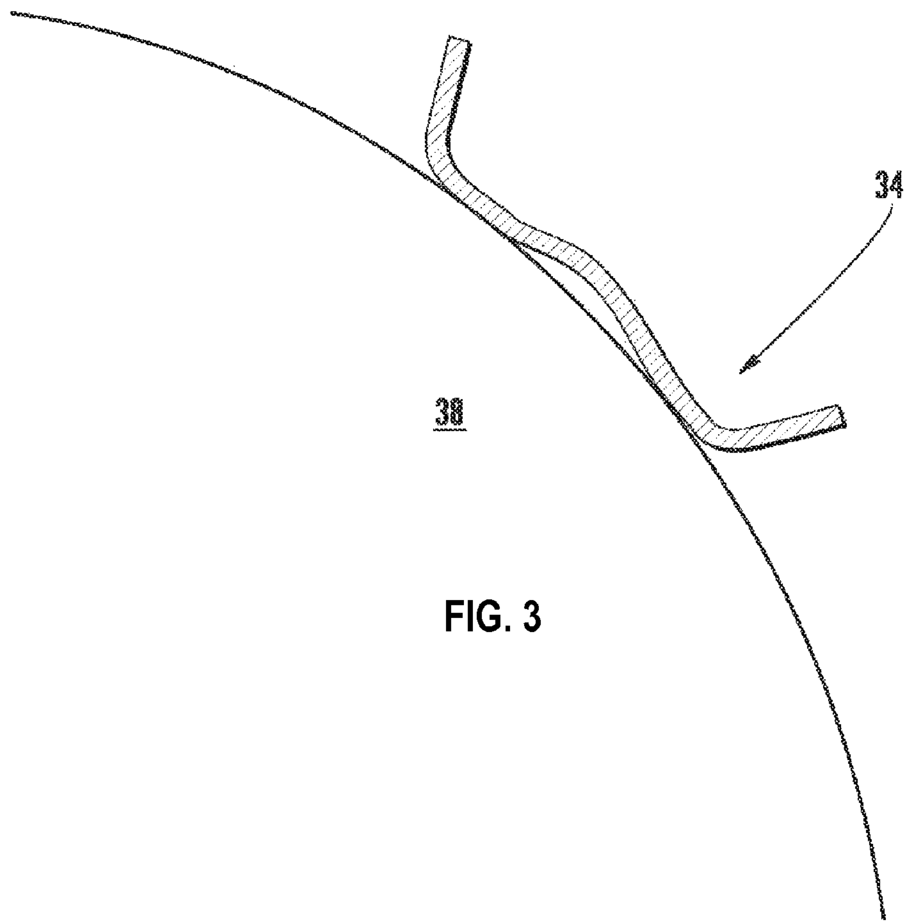

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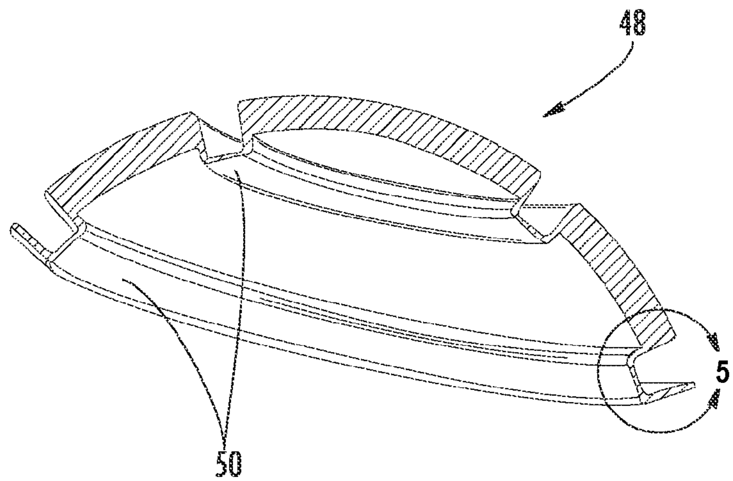

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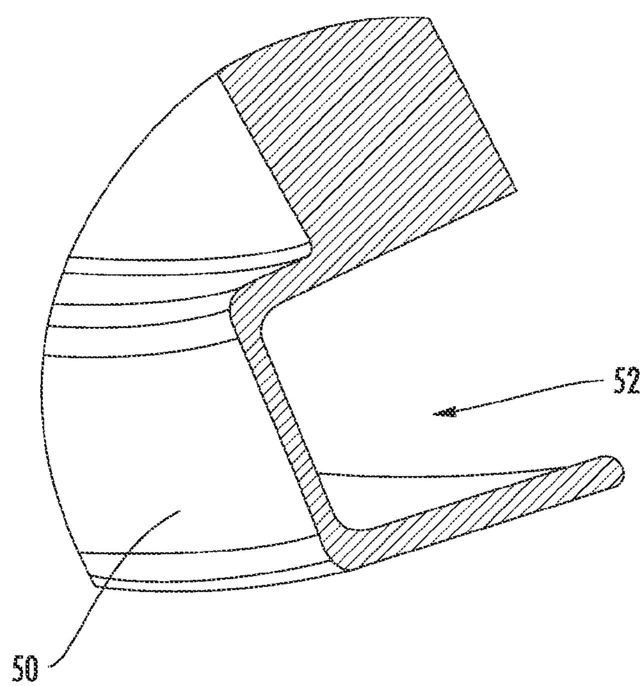


FIG. 5

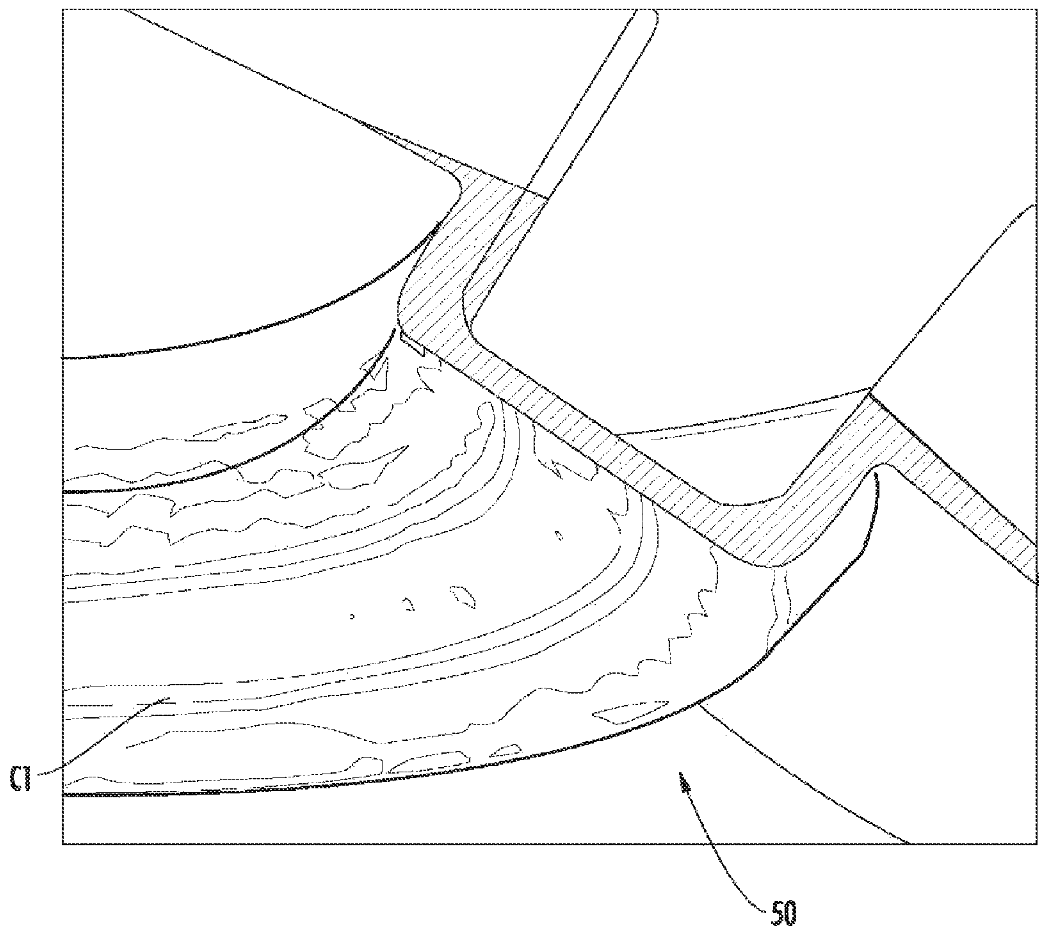


FIG. 6

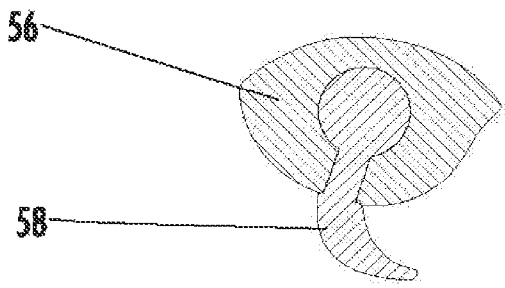
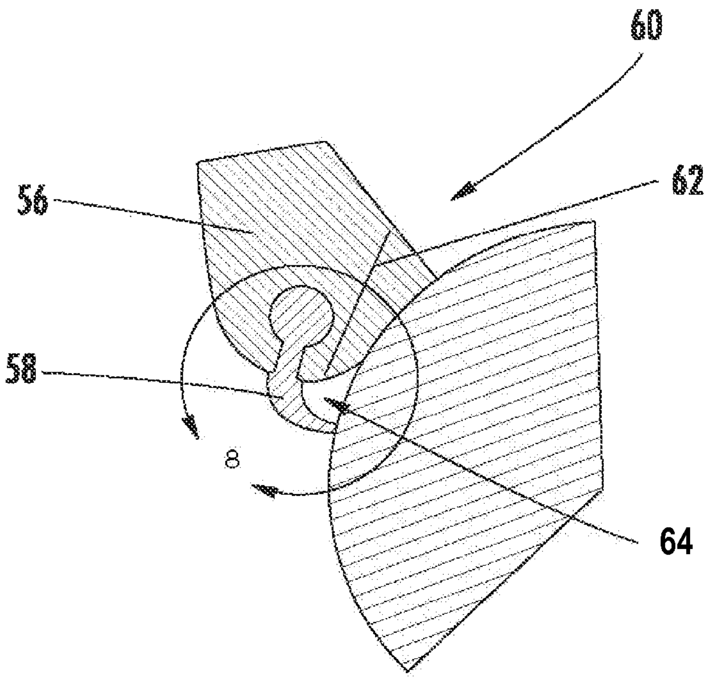


FIG. 8



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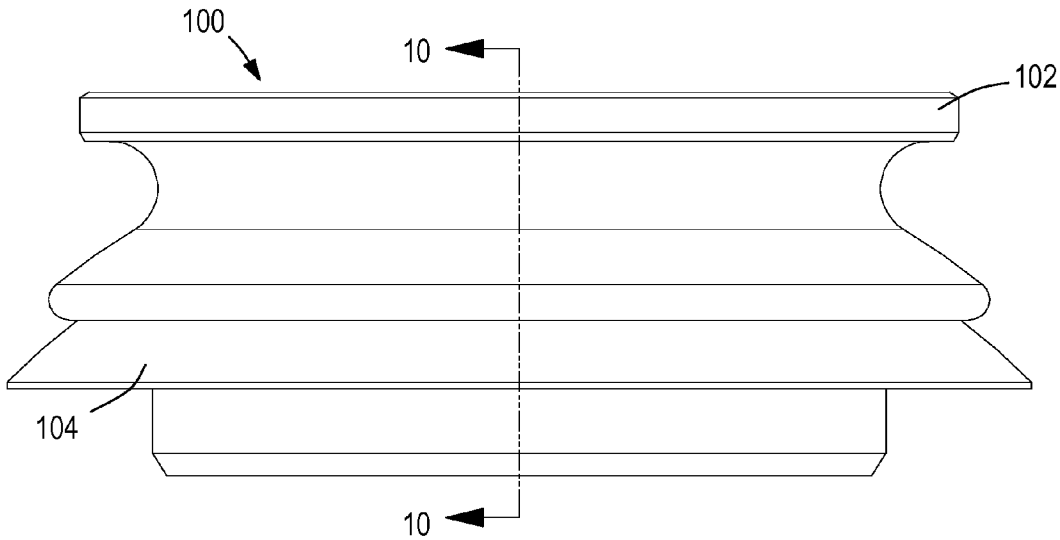

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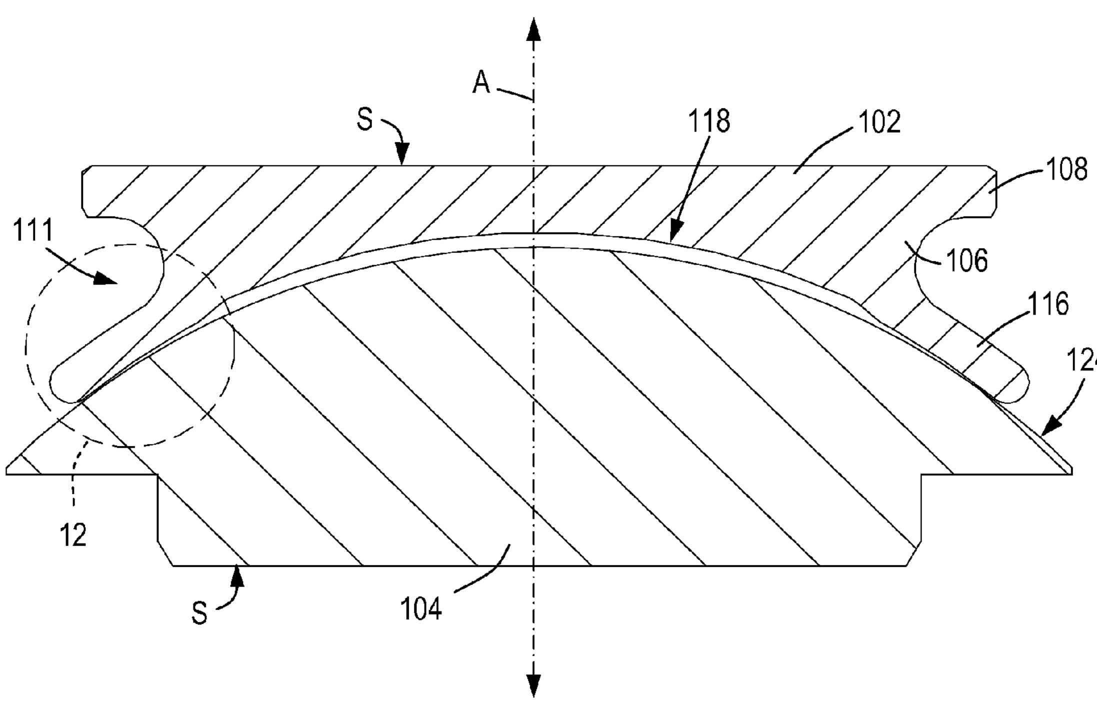

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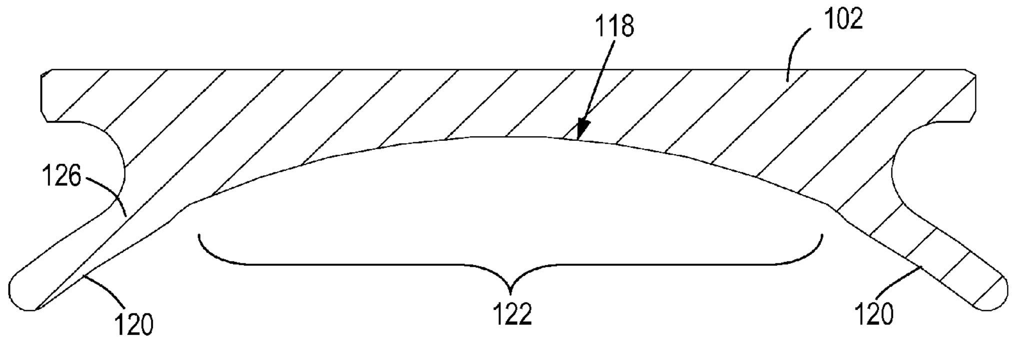

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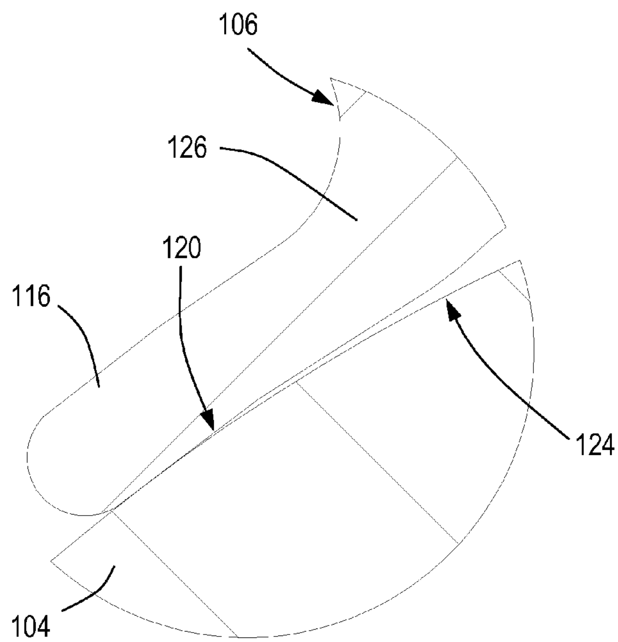

FIG. 12

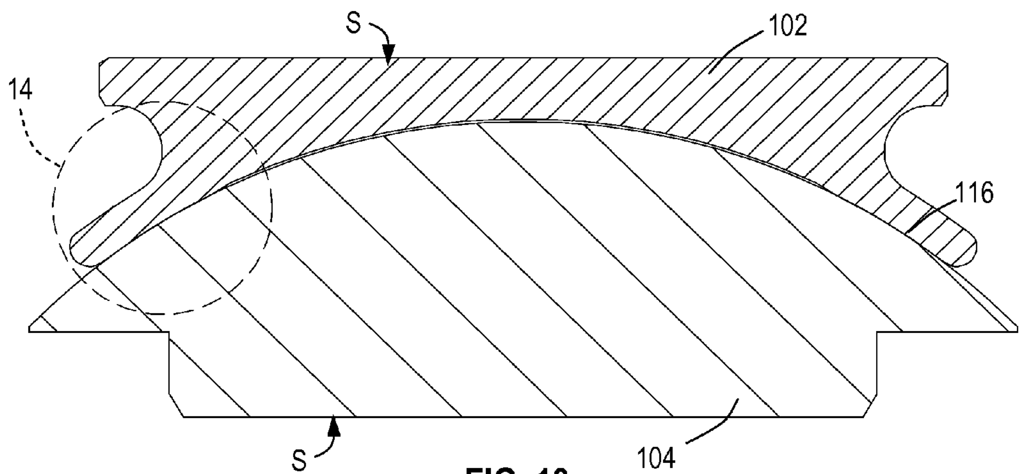

FIG. 13

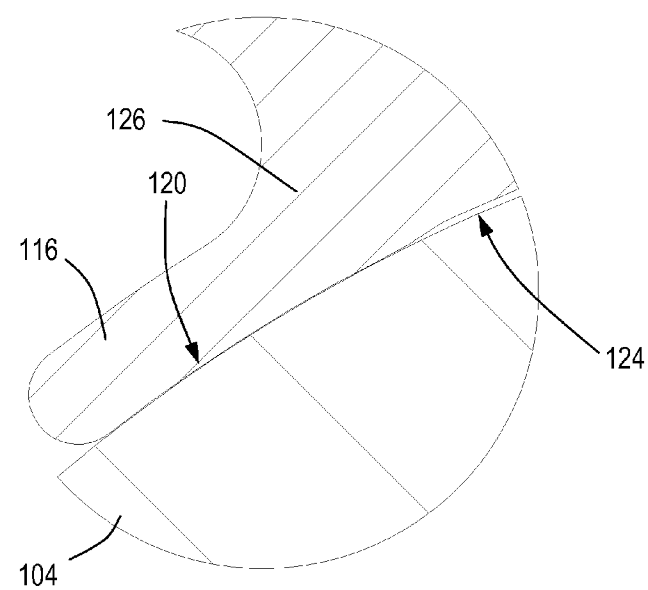

FIG. 14

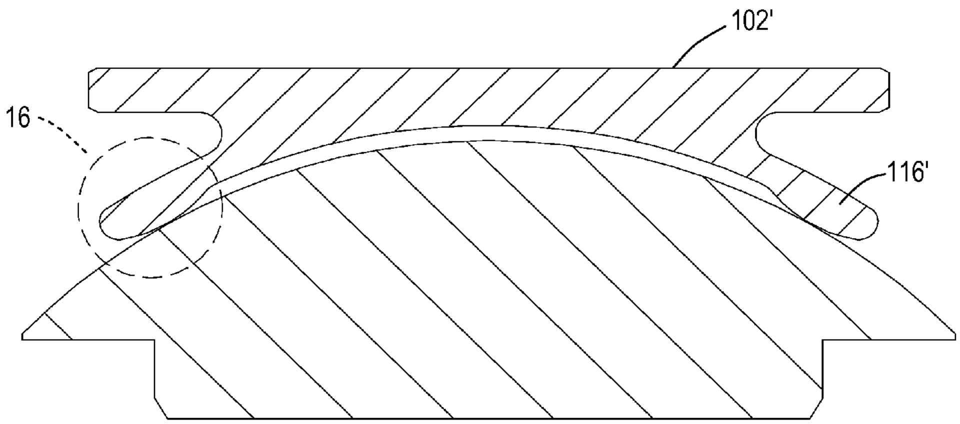

FIG. 15

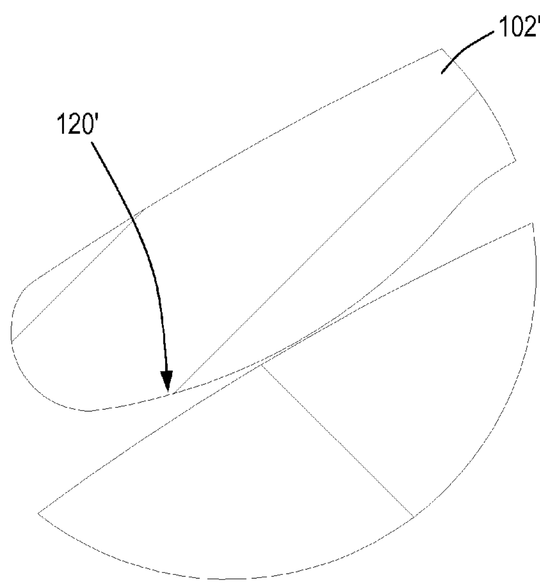

FIG. 16

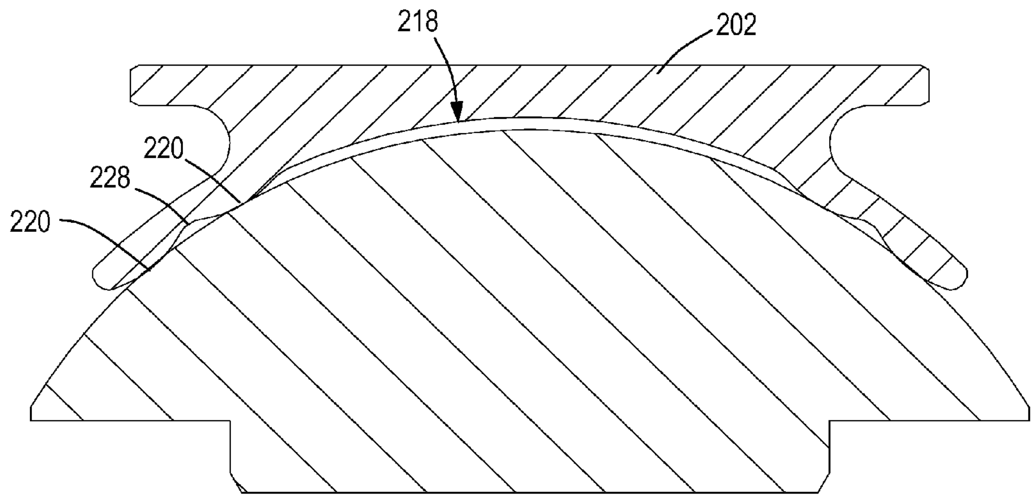

FIG. 17

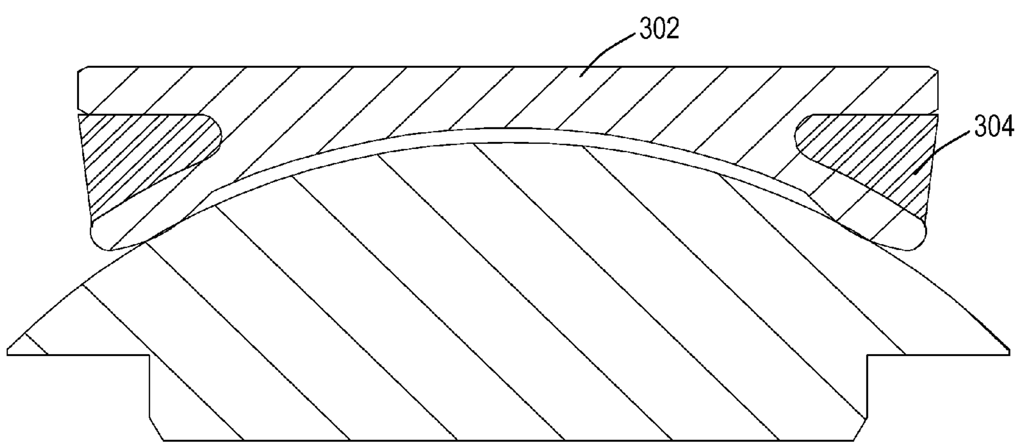

FIG. 18

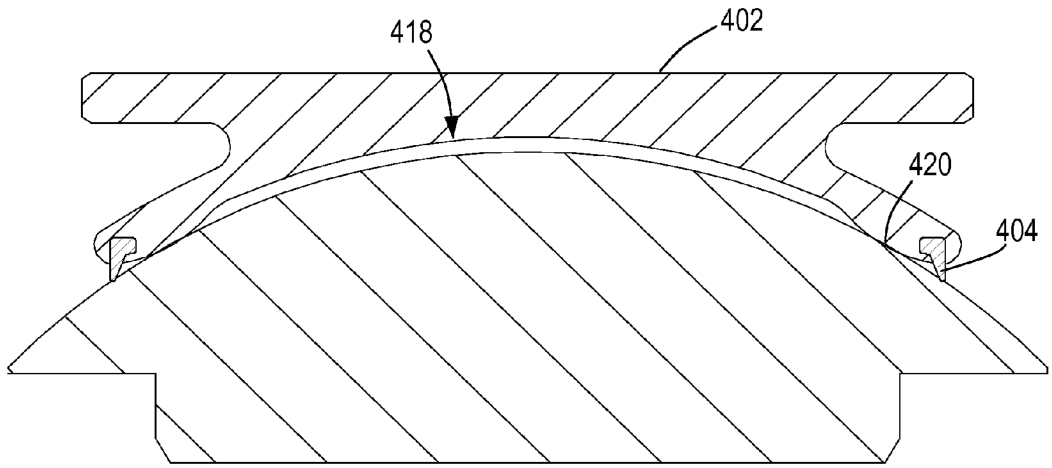
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FIG. 19

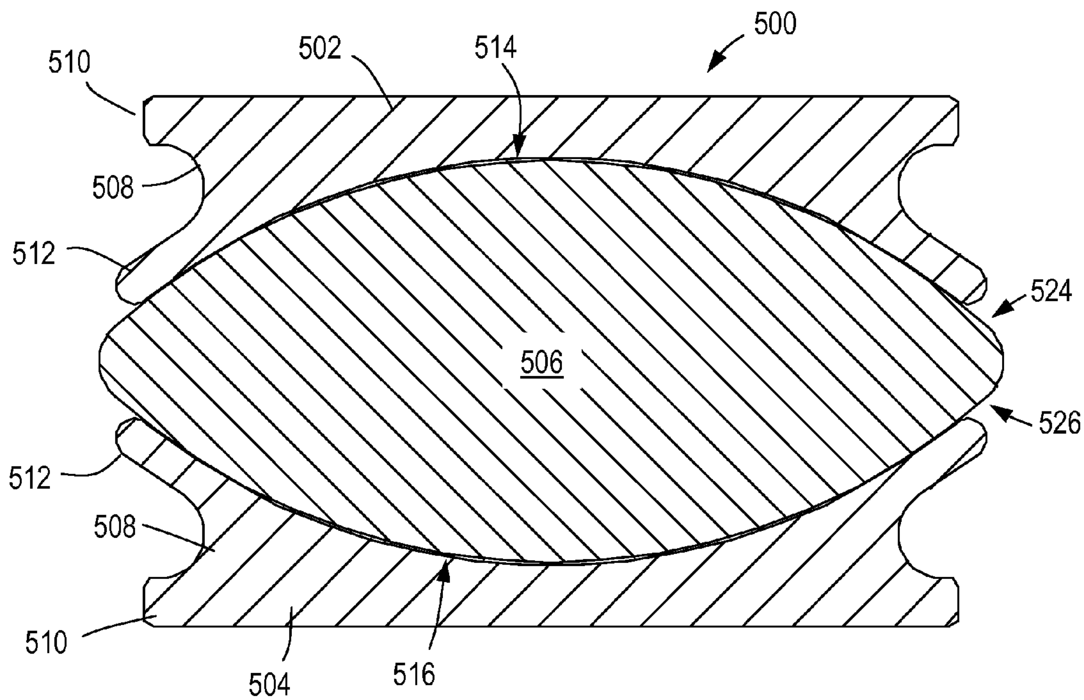
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FIG. 20

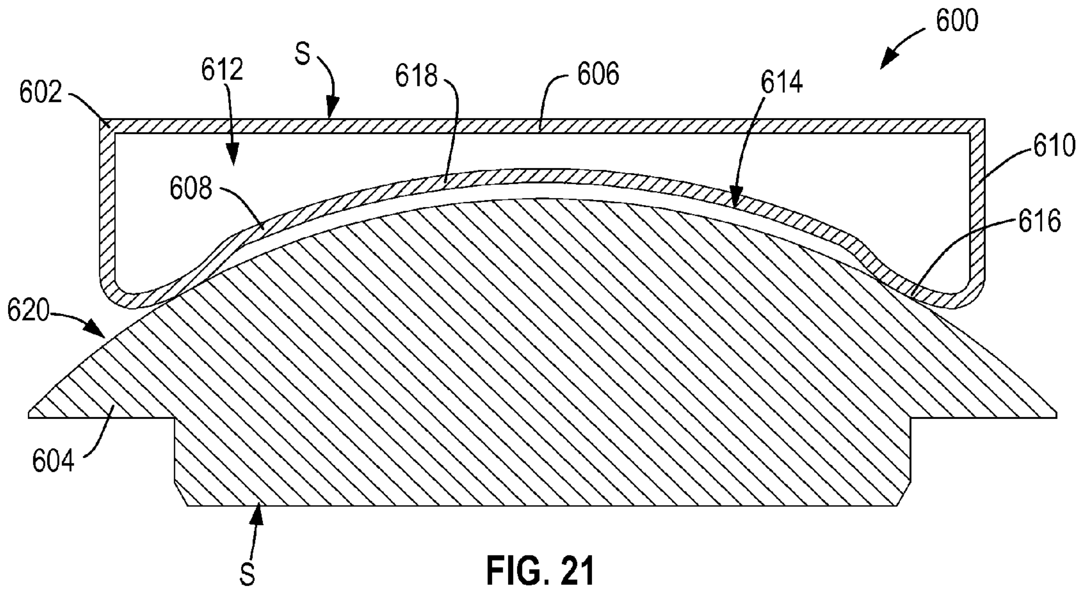
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FIG. 21

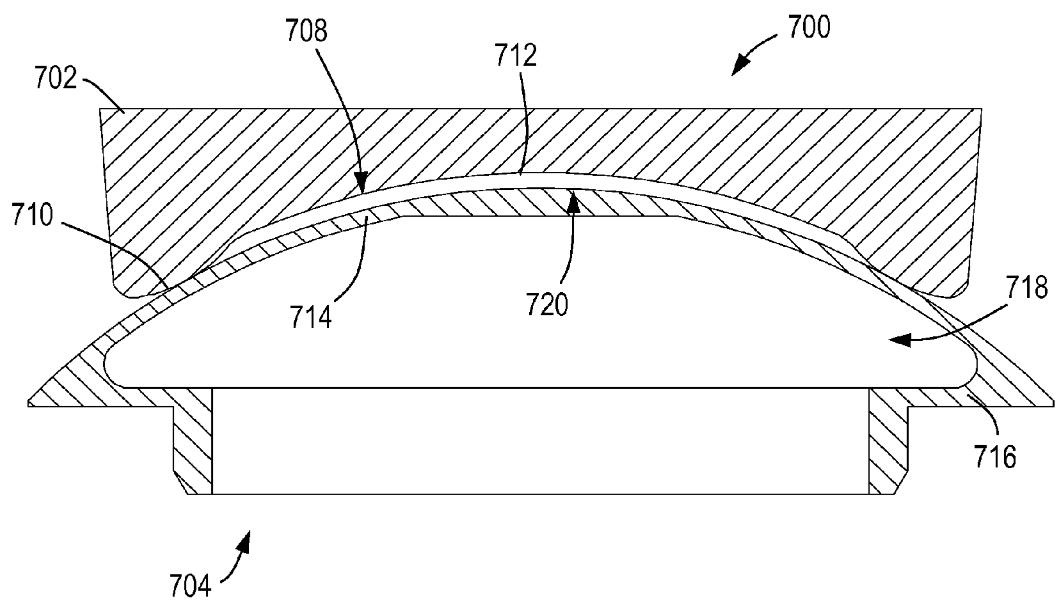
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FIG. 22

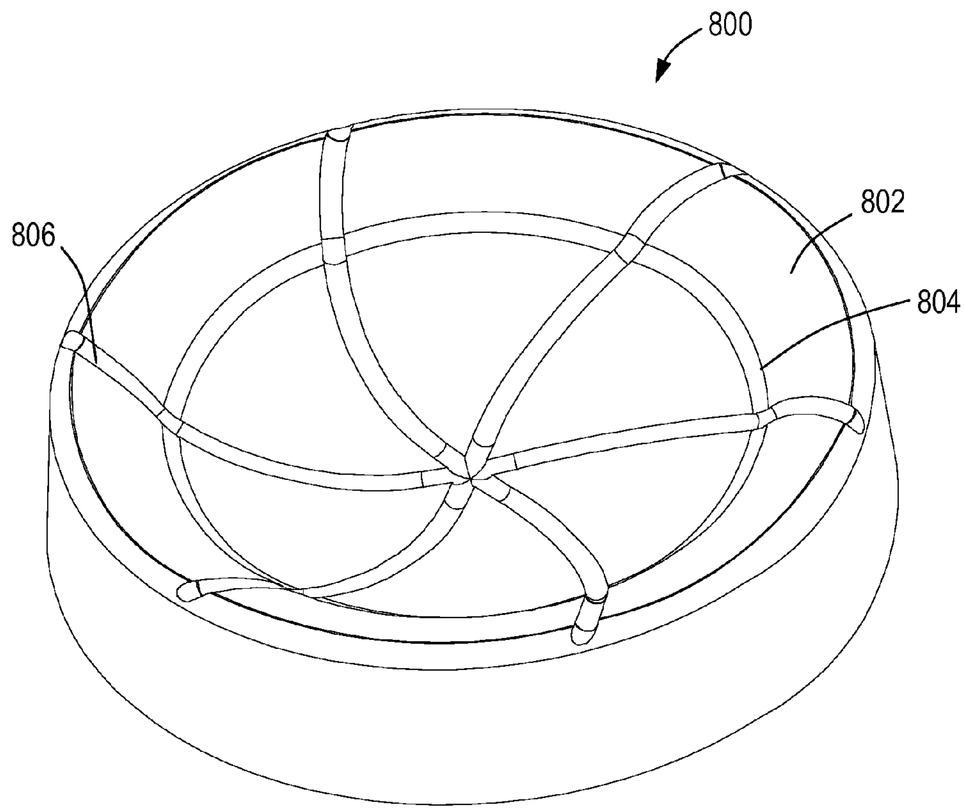


FIG. 23

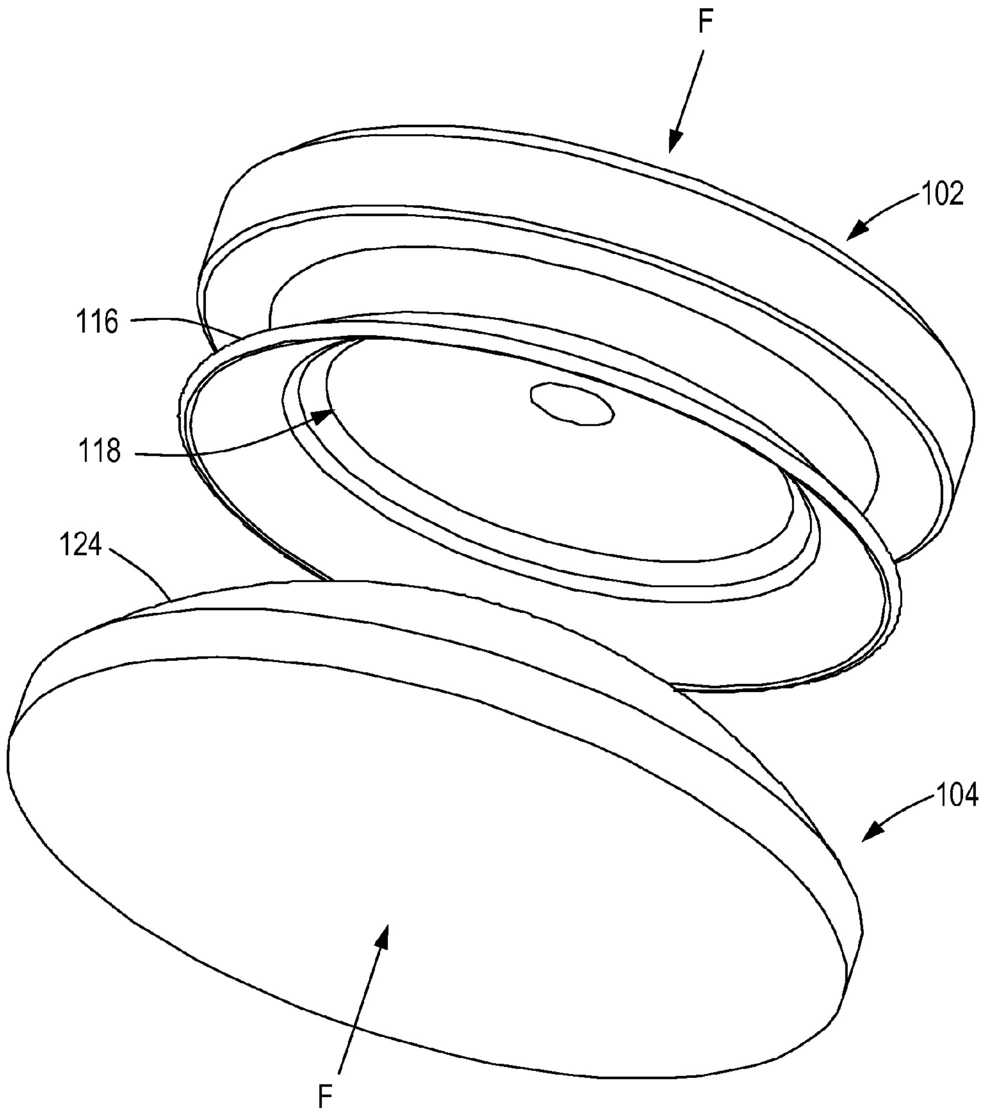


FIG. 24

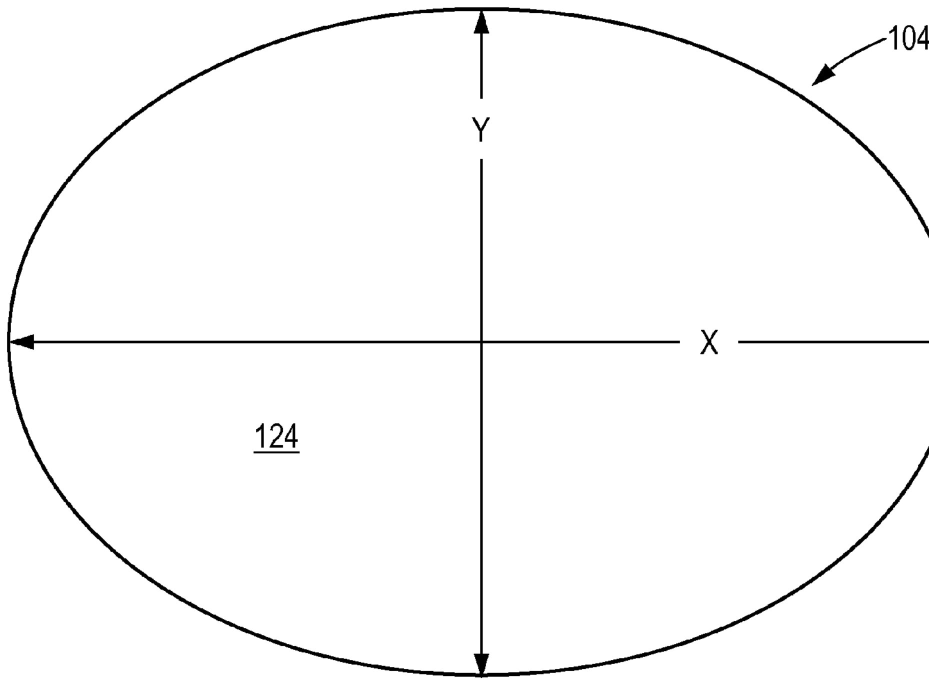
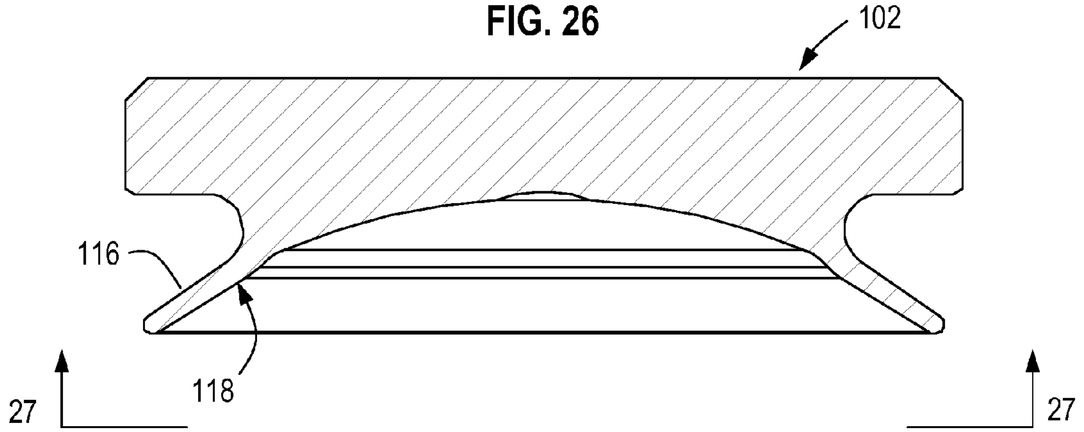
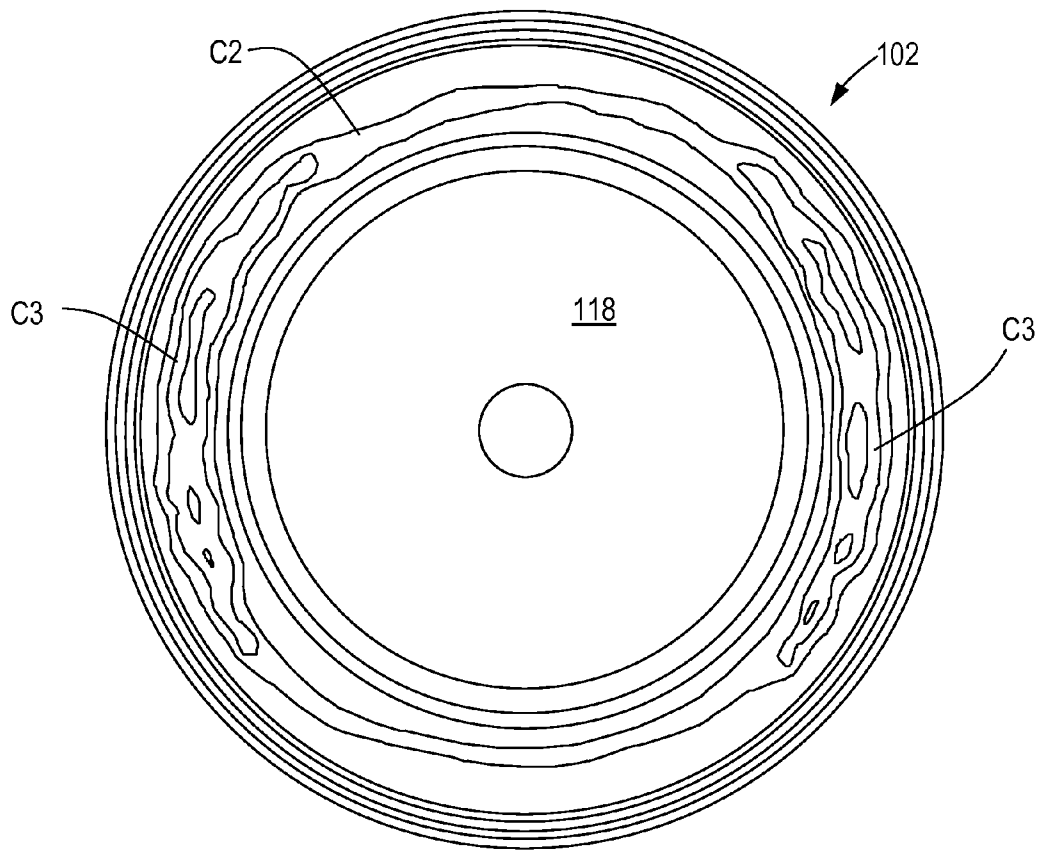


FIG. 25

FIG. 26





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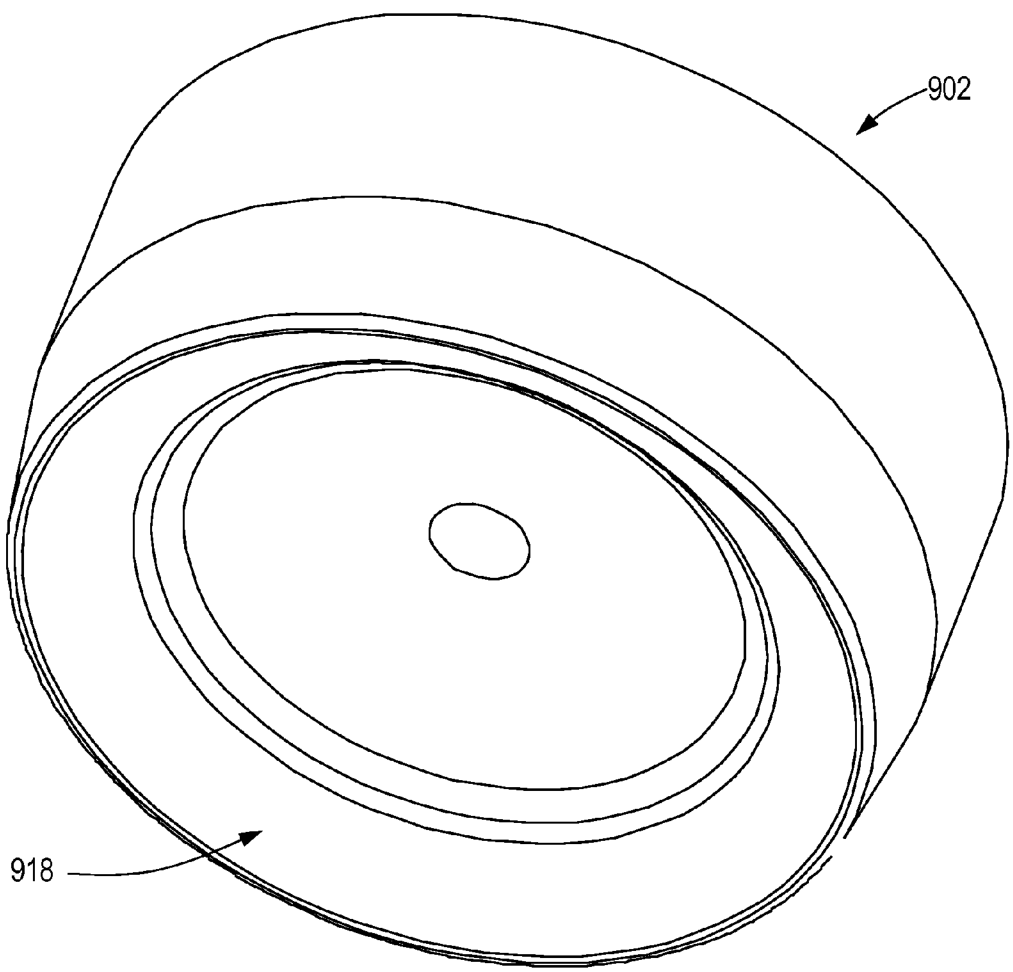

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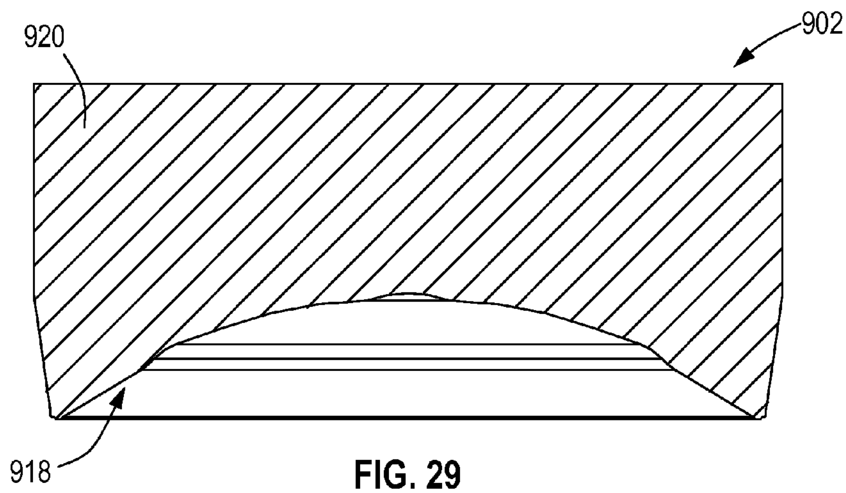

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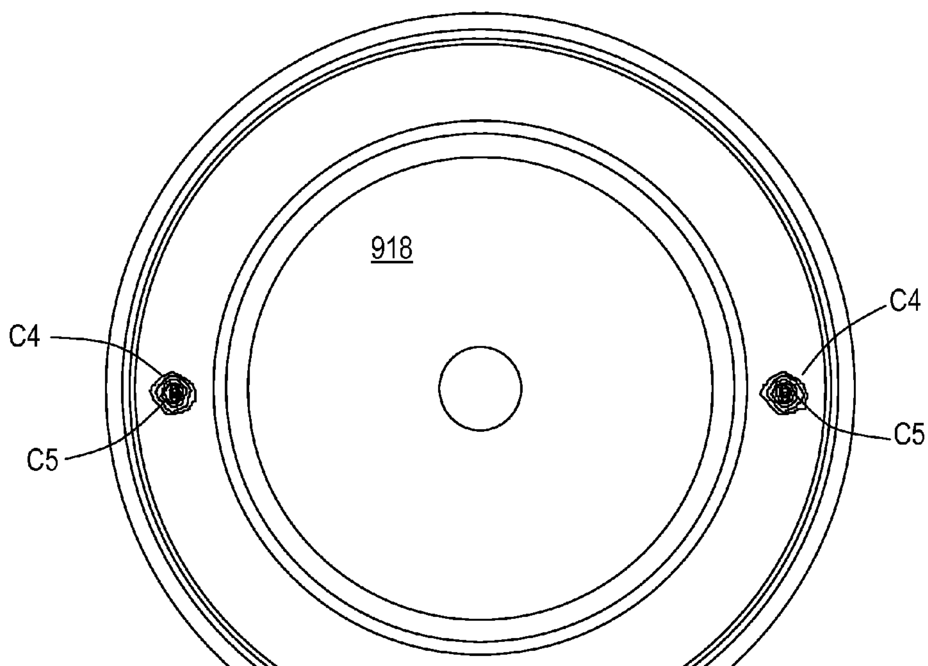

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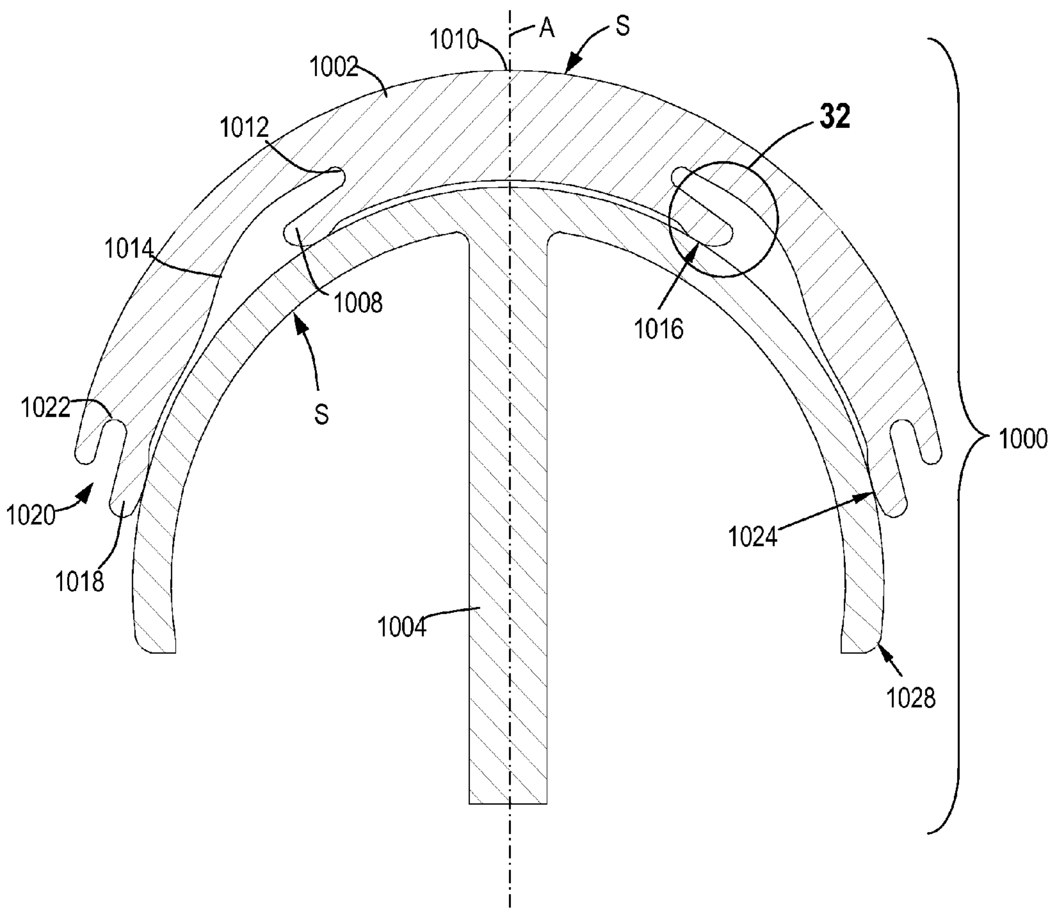
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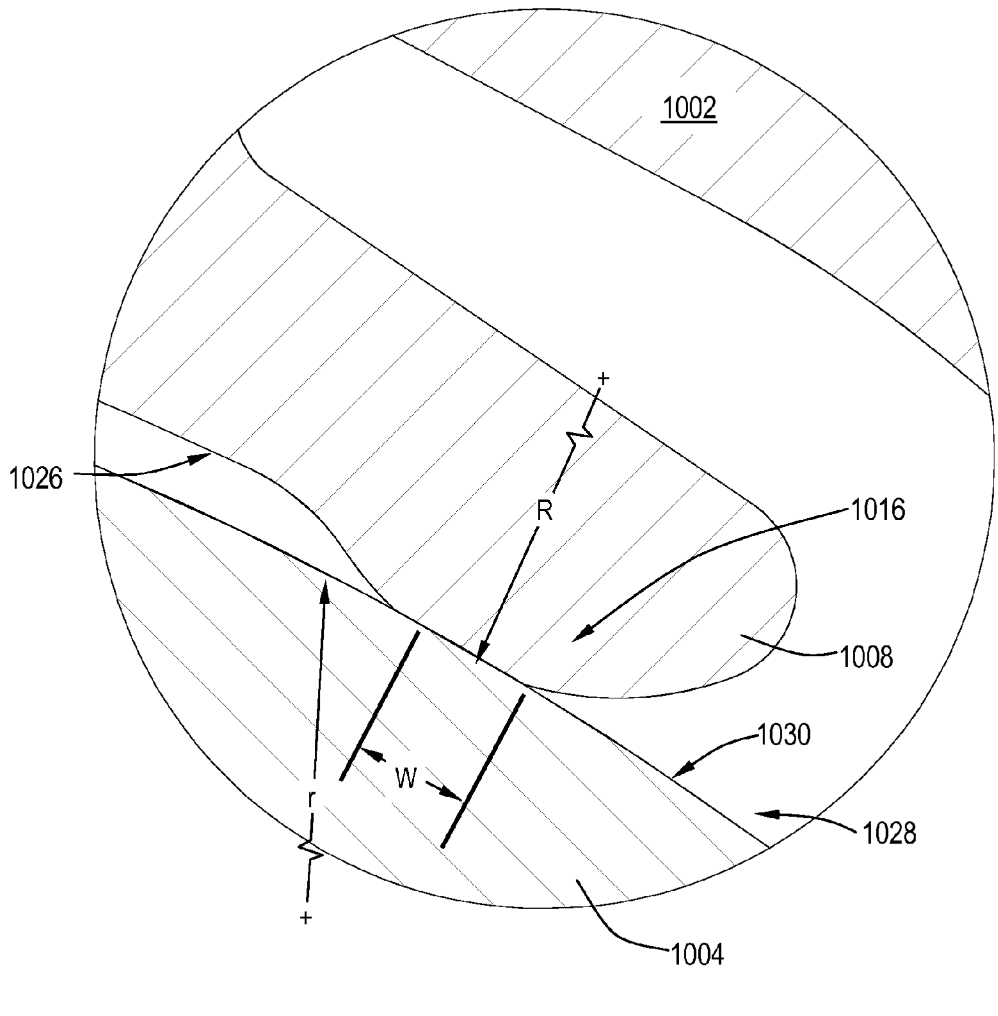
FIG. 31



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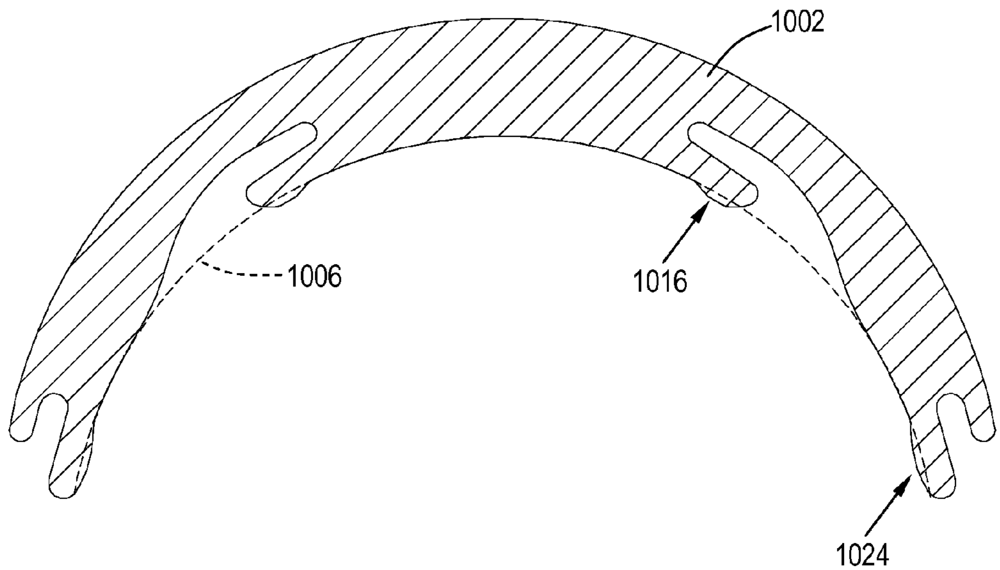


FIG. 33

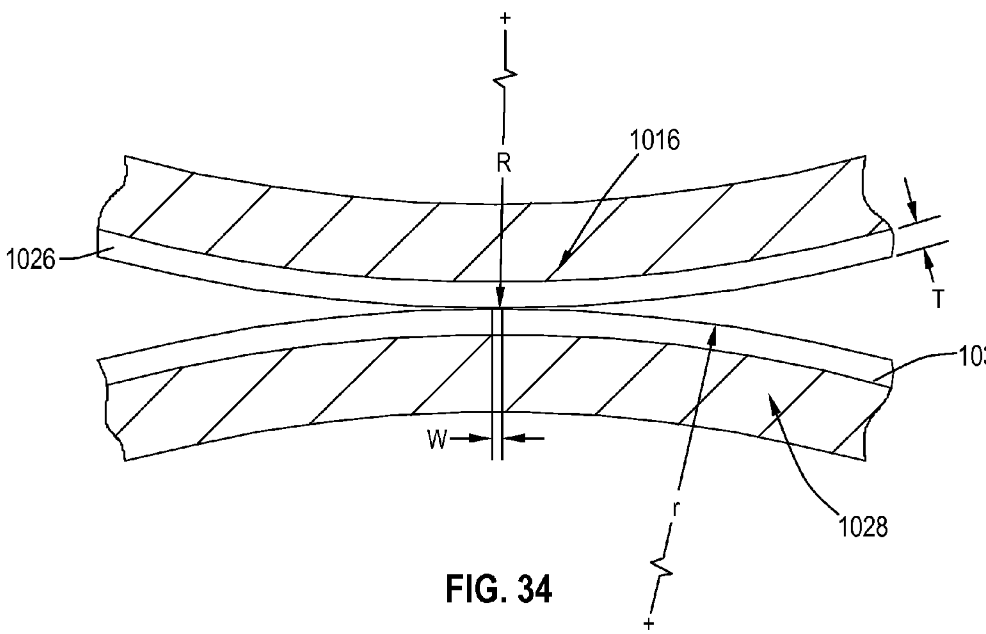


FIG. 34

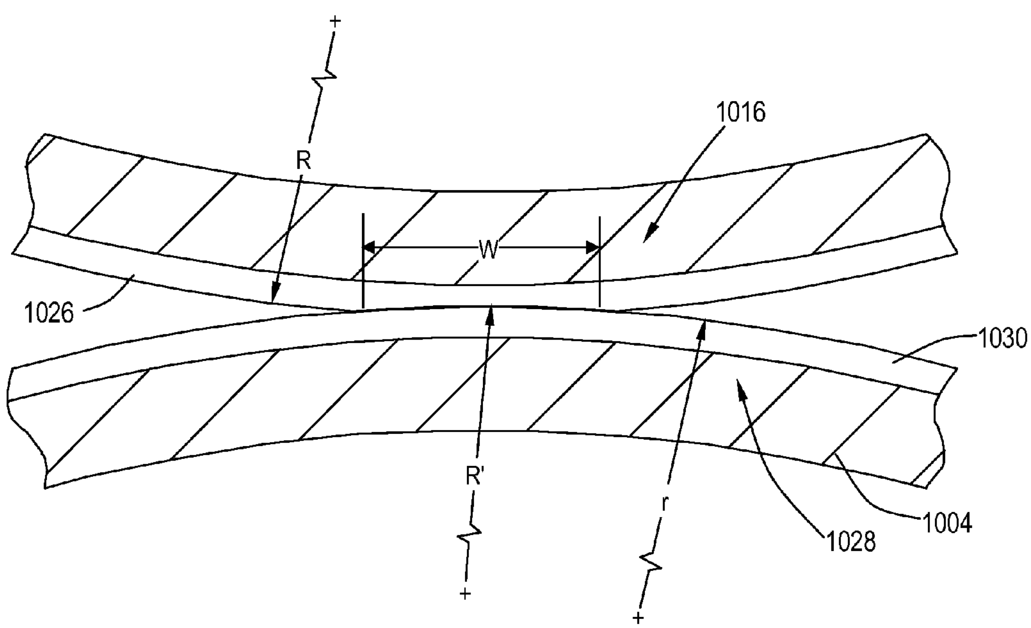


FIG. 35

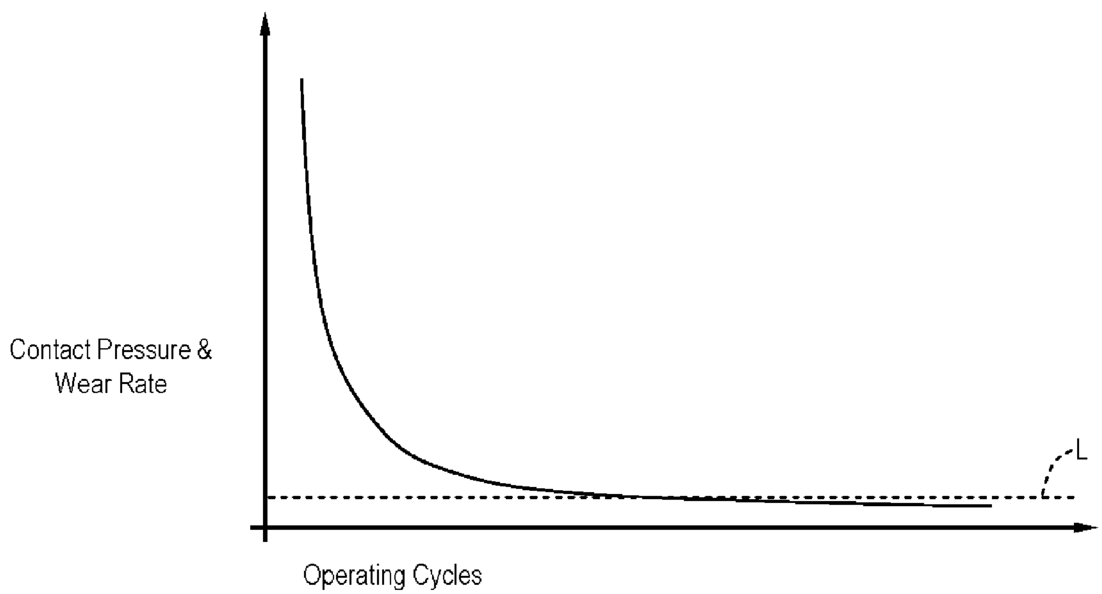
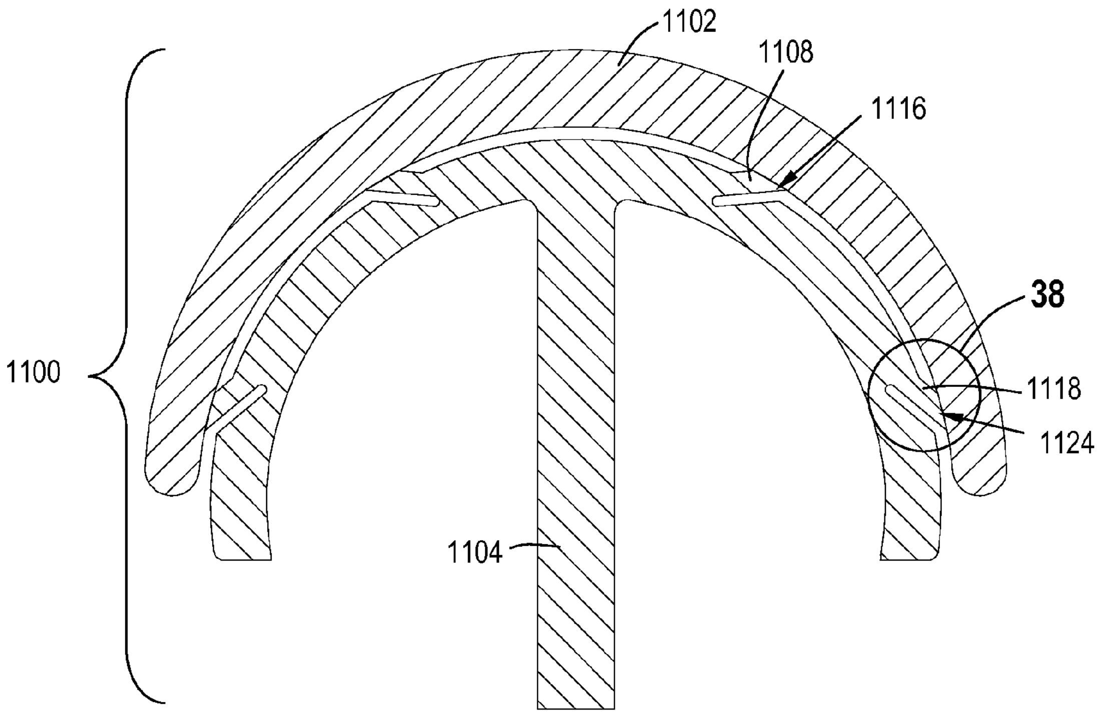


FIG. 36



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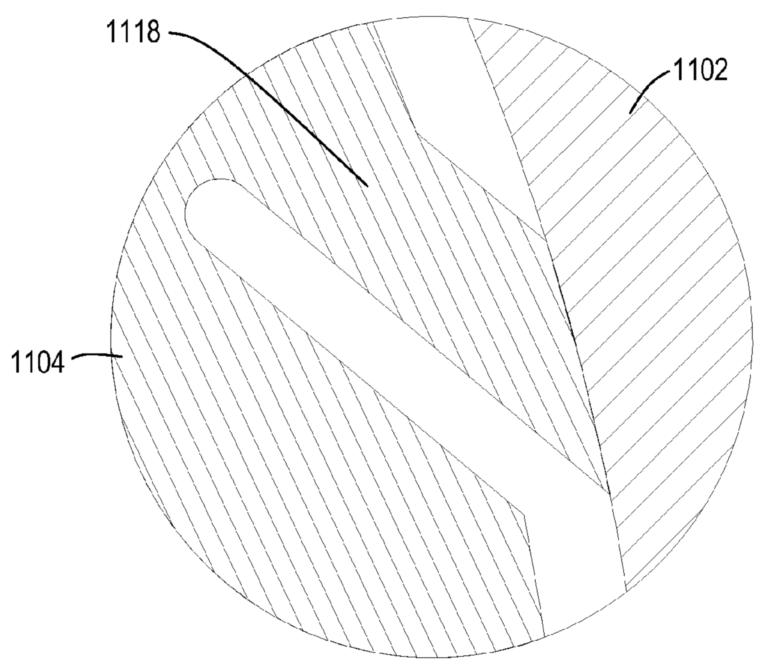

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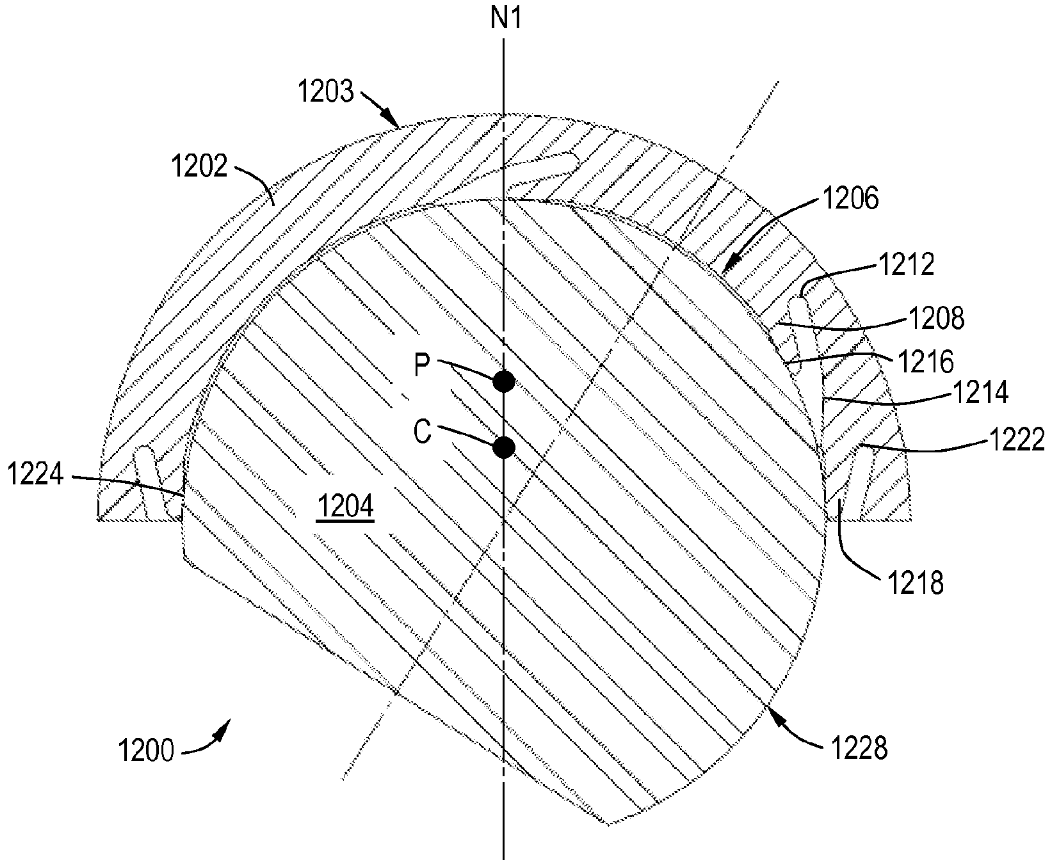
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FIG. 39

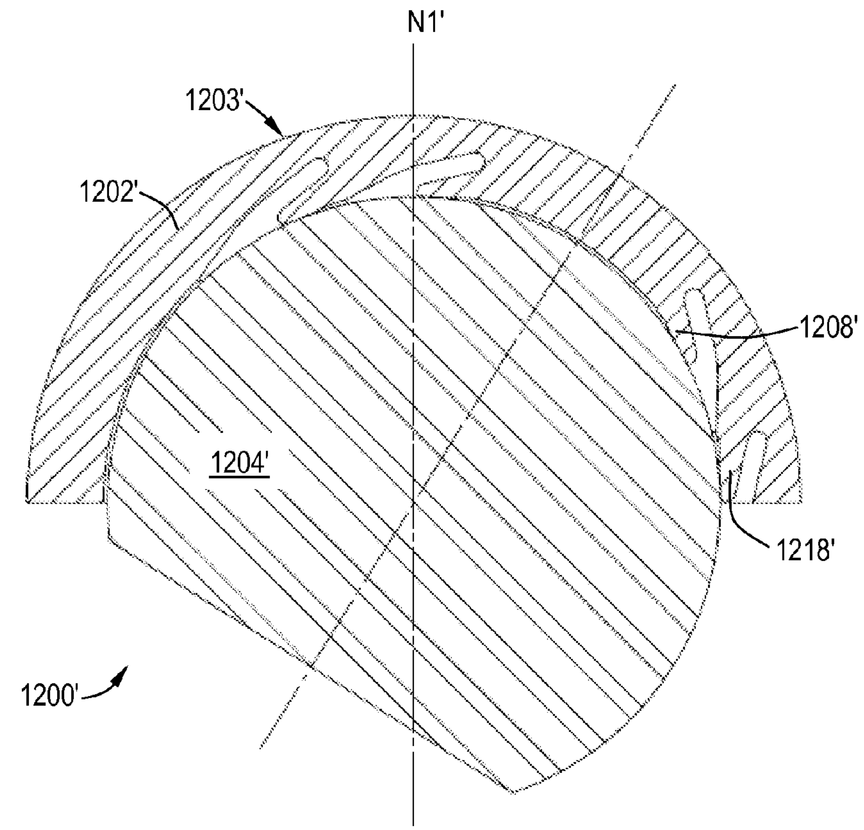


FIG. 40

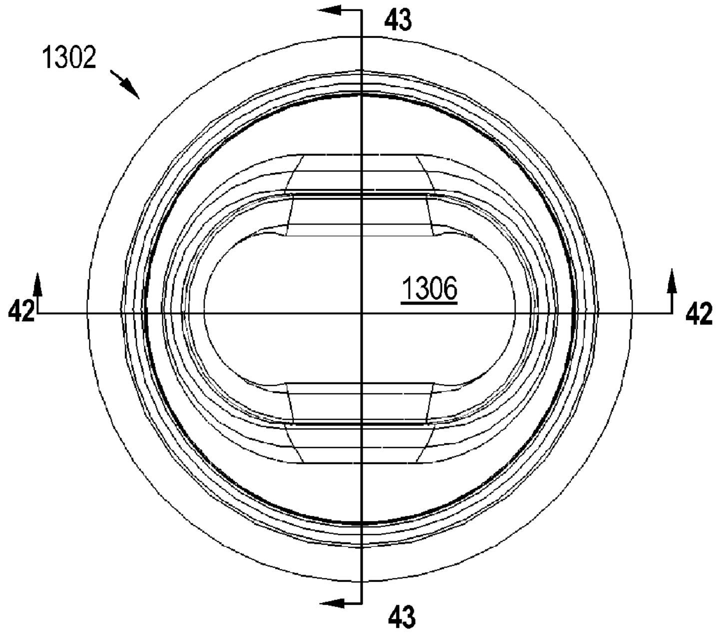


FIG. 41

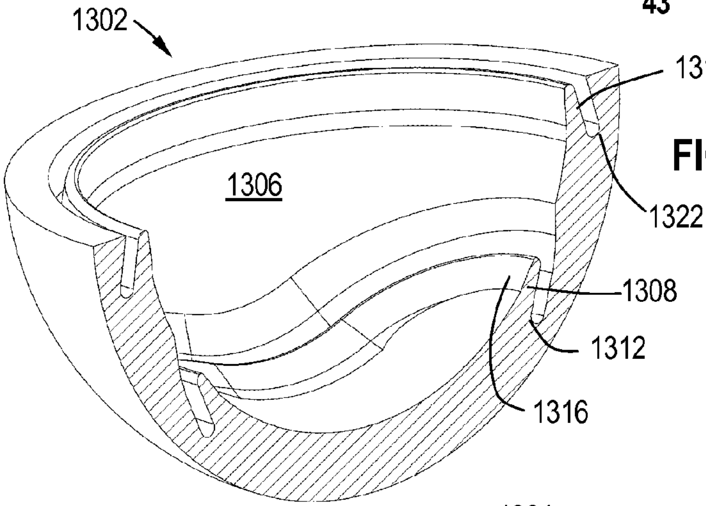


FIG. 42

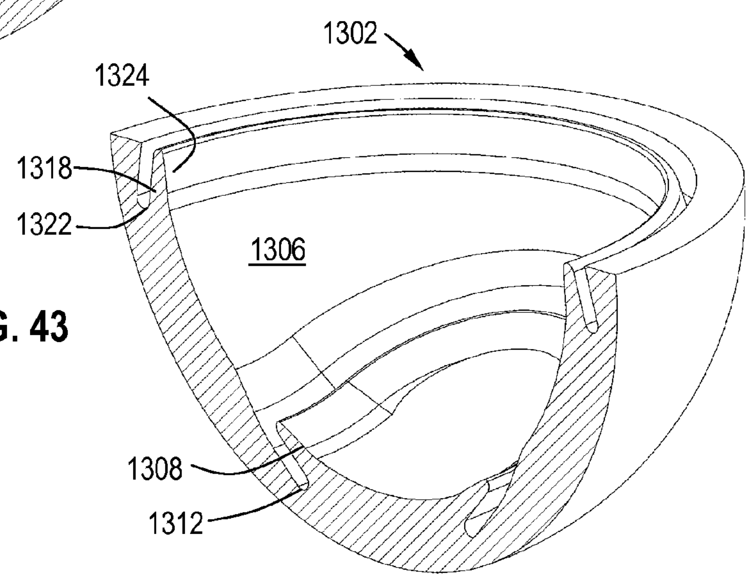
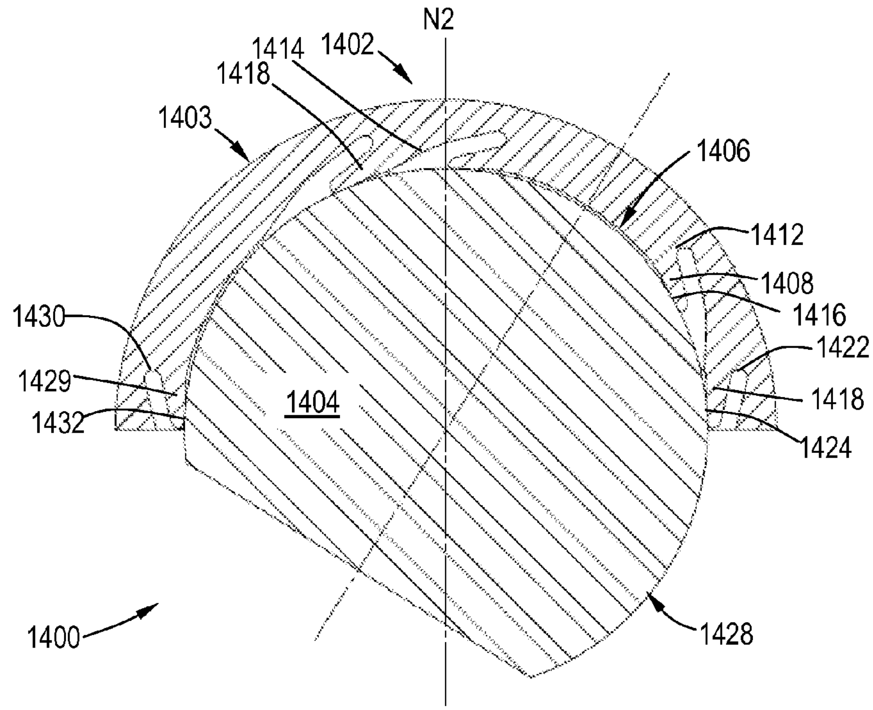


FIG. 43

FIG. 44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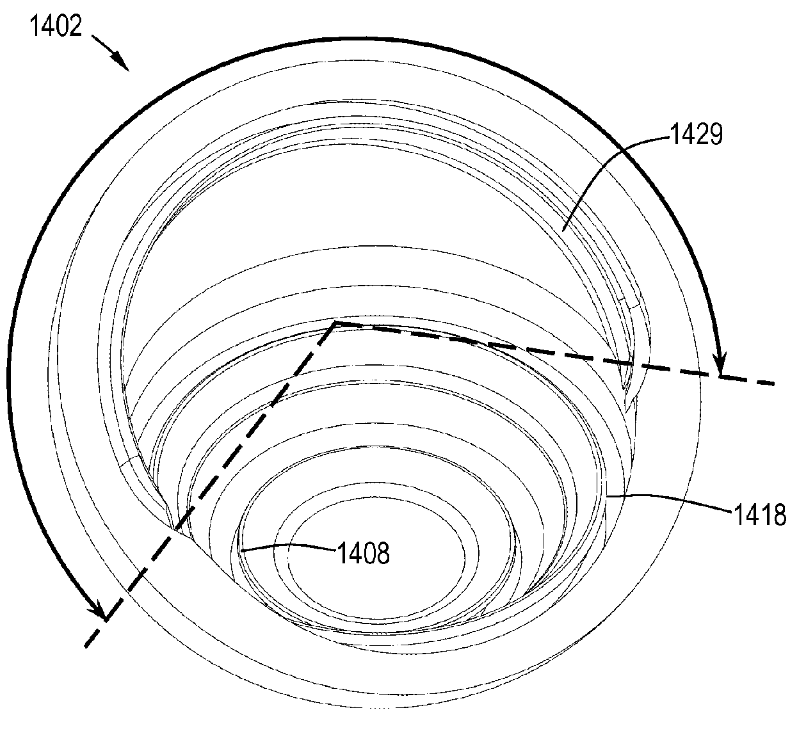
1400
1428

FIG. 45


1402
1429
1418
1408

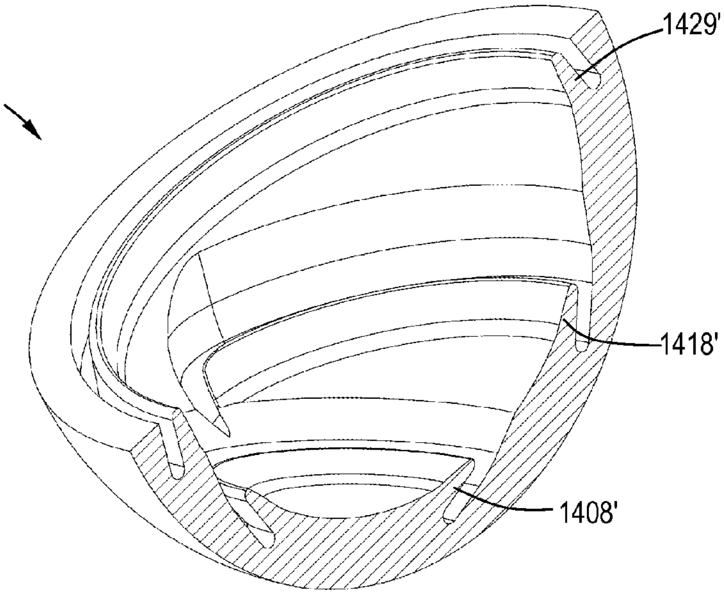


FIG. 46

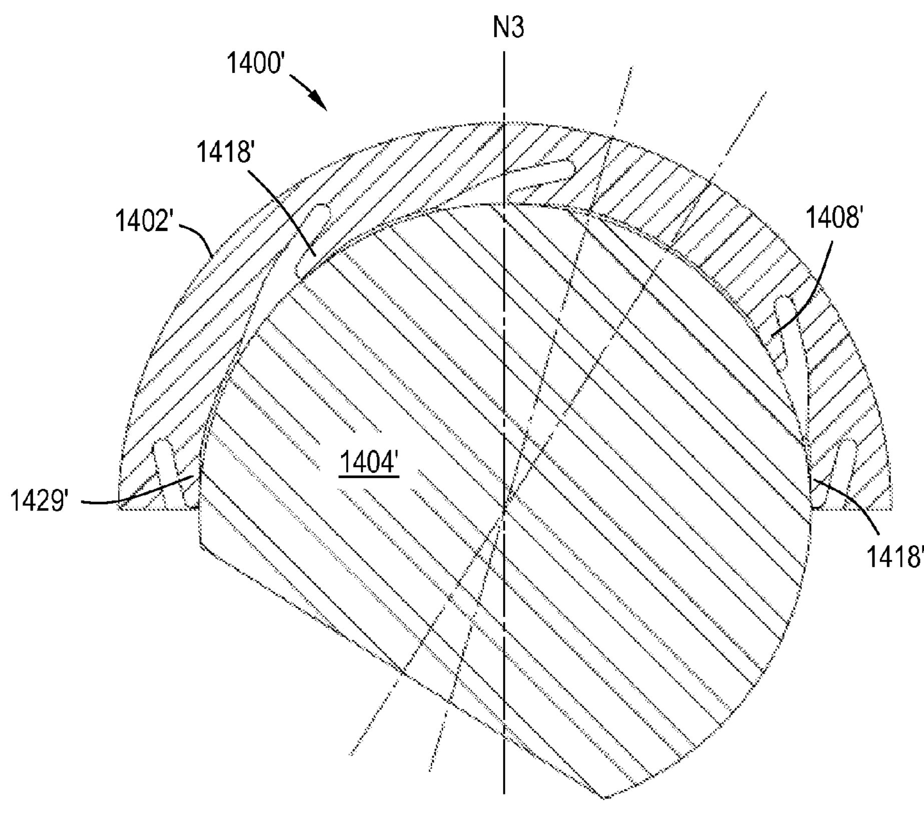


FIG. 47

FIG. 48

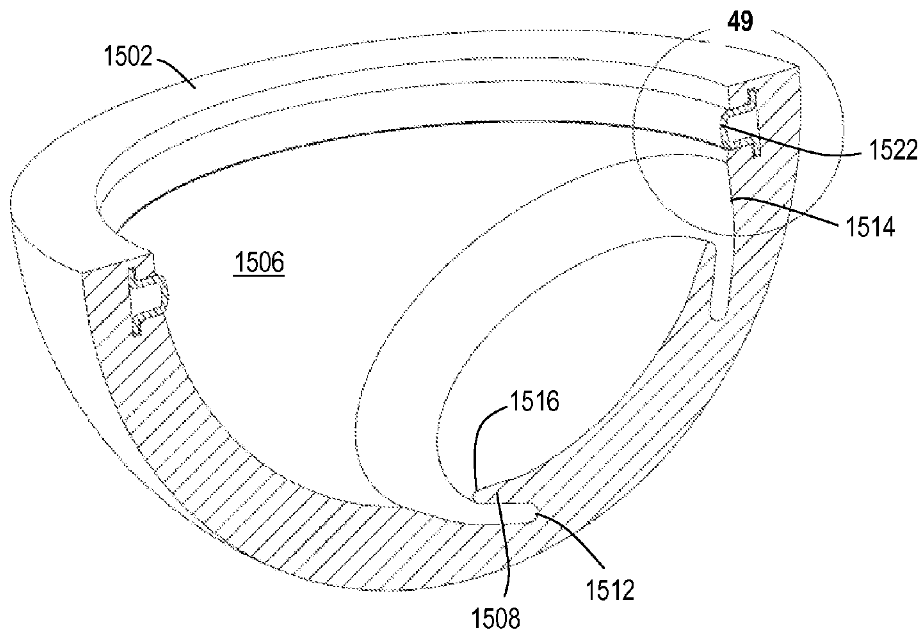

49
1502
1522
1514
1506
1516
1512
1508

FIG. 49

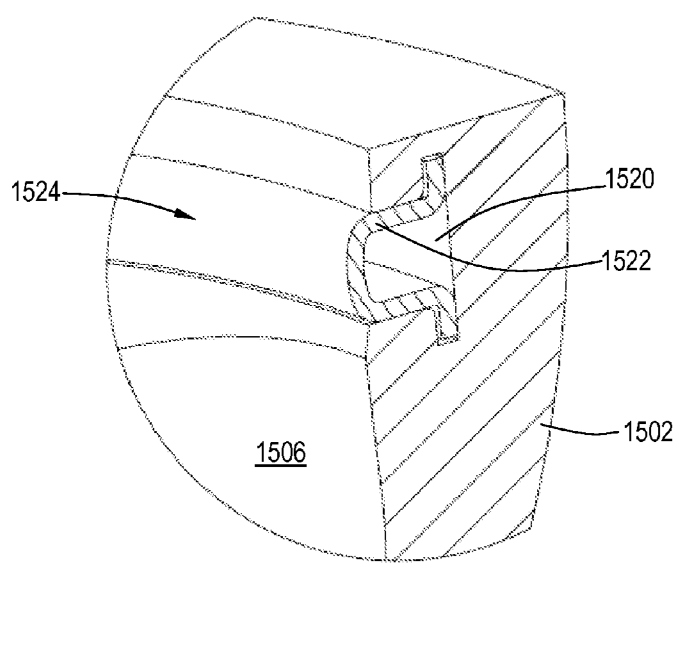

1524
1520
1522
1506
1502

FIG. 50

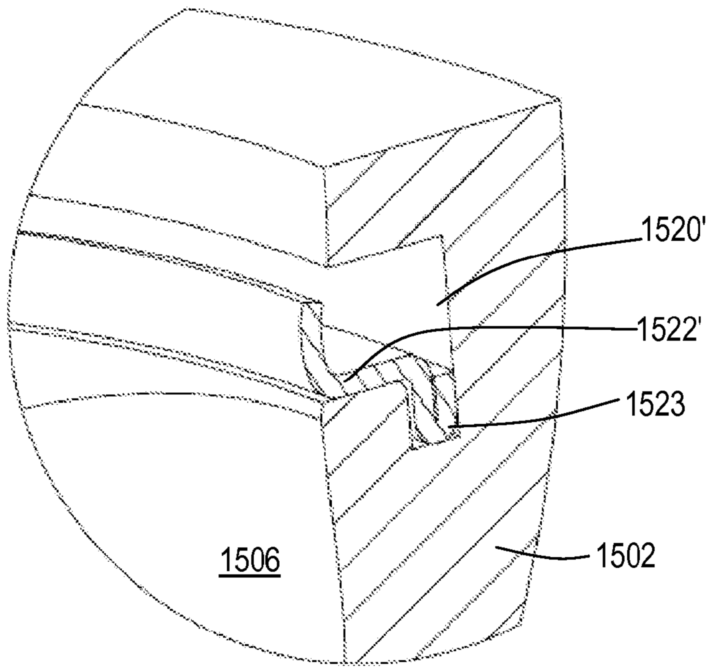
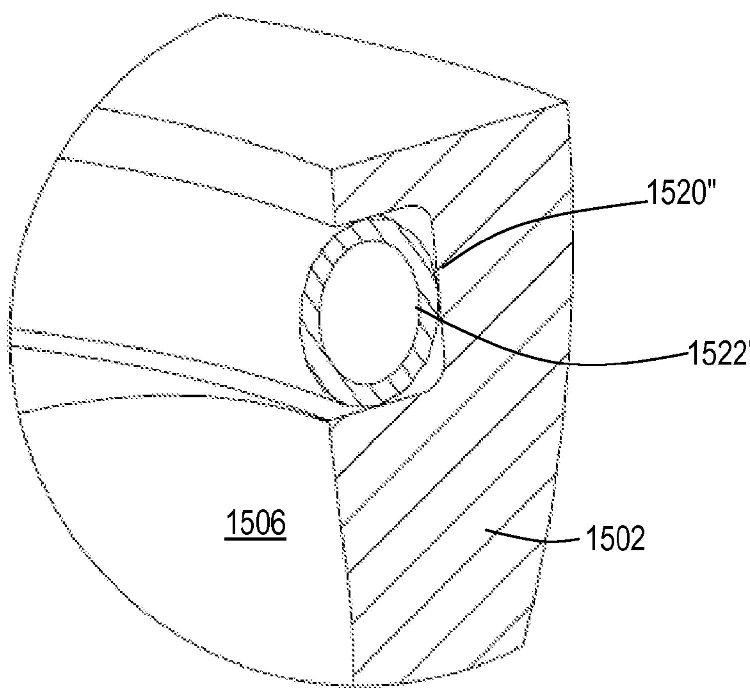


FIG. 51



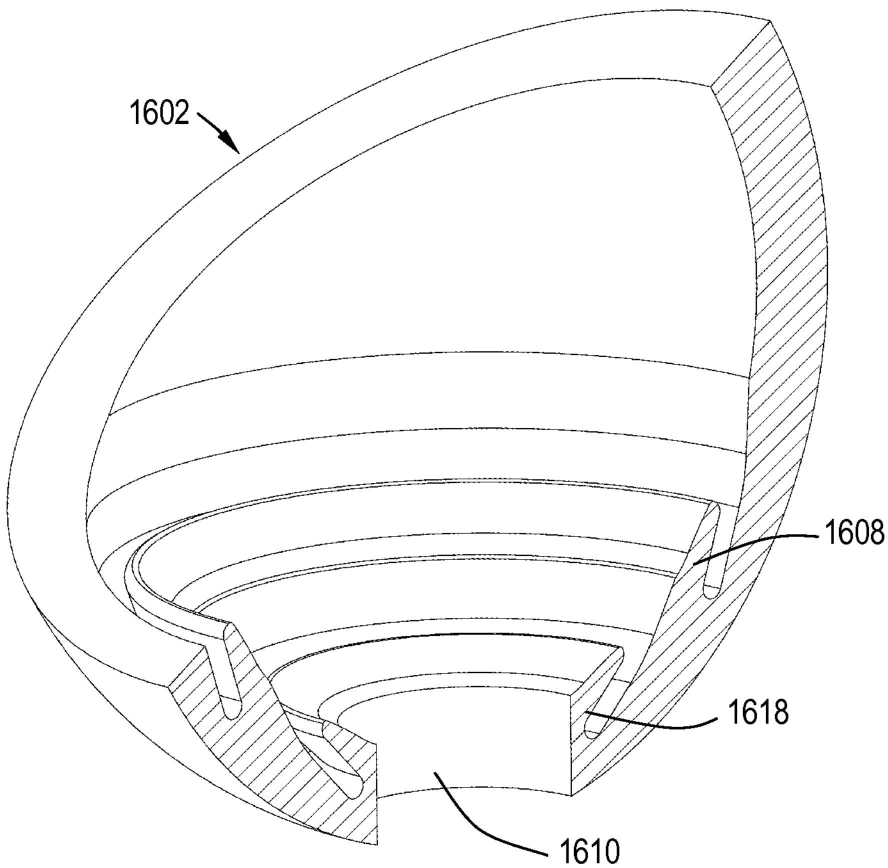


FIG. 52

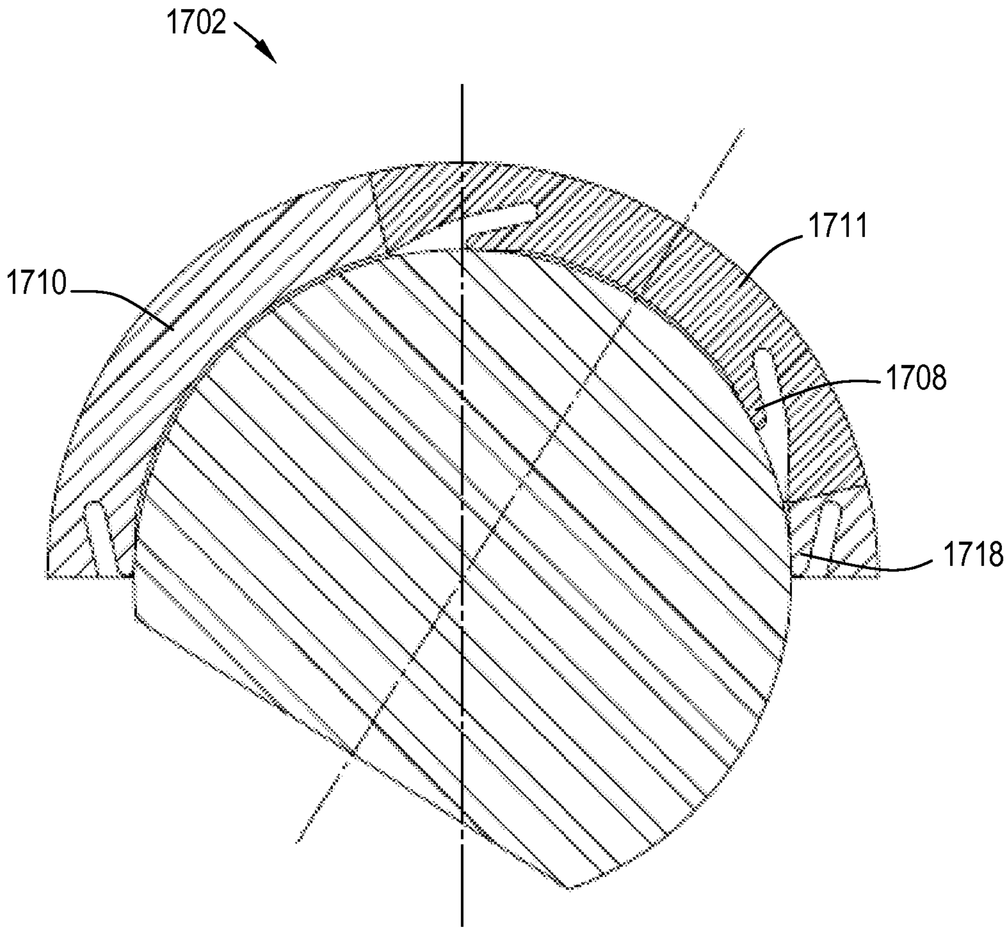


FIG. 53

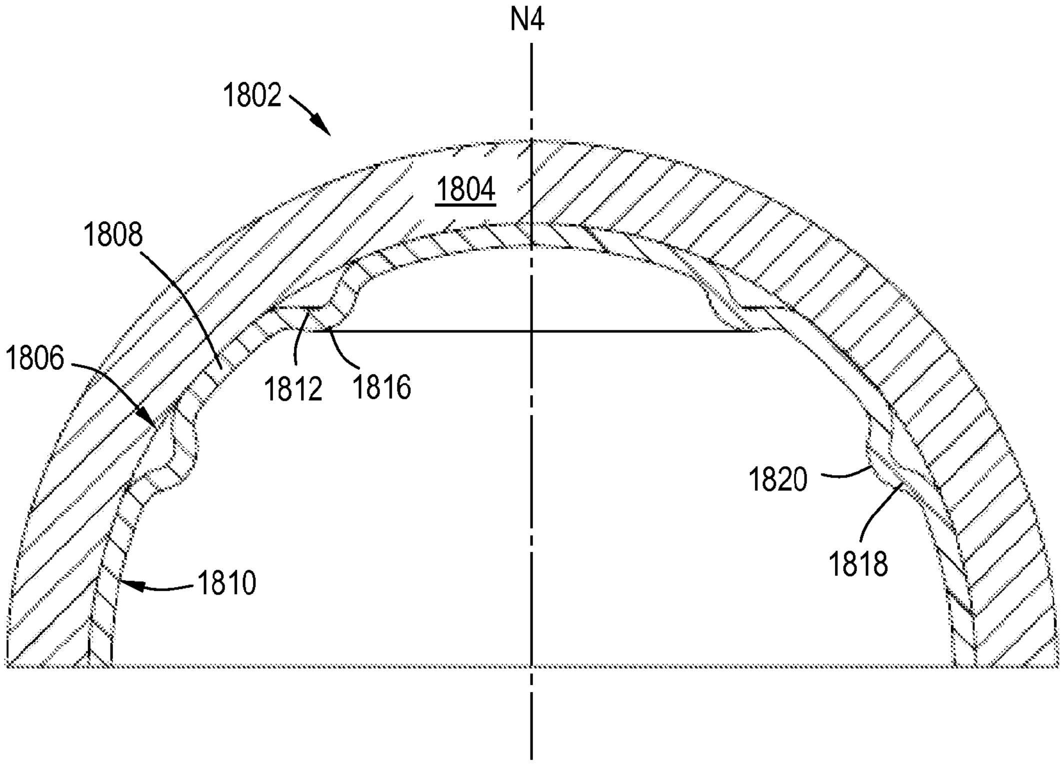


FIG. 54

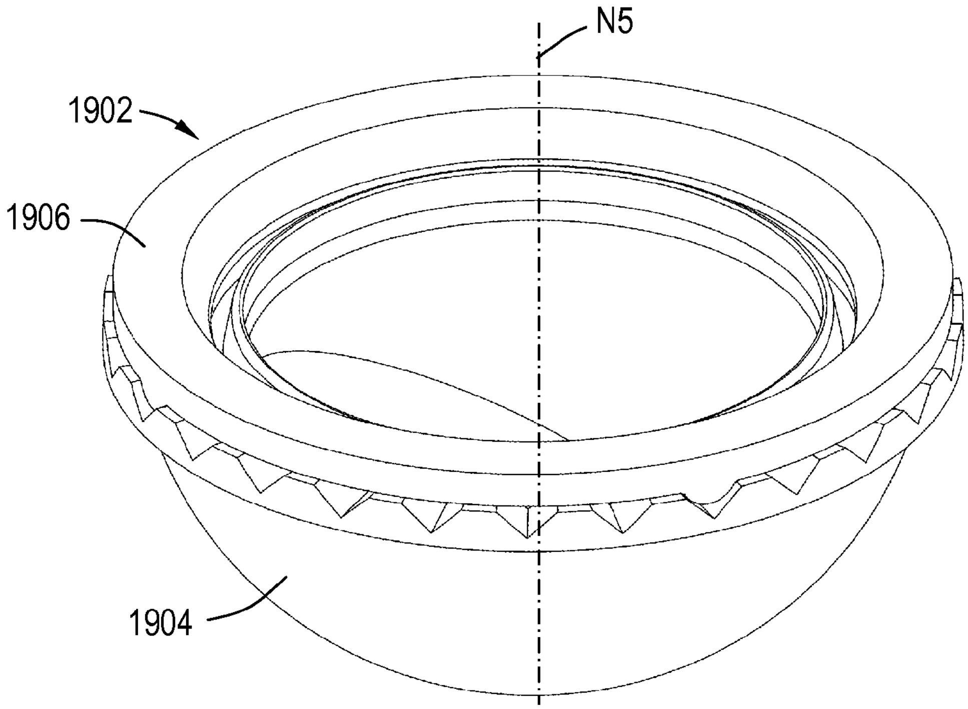

N5
1902
1906
1904

FIG. 55

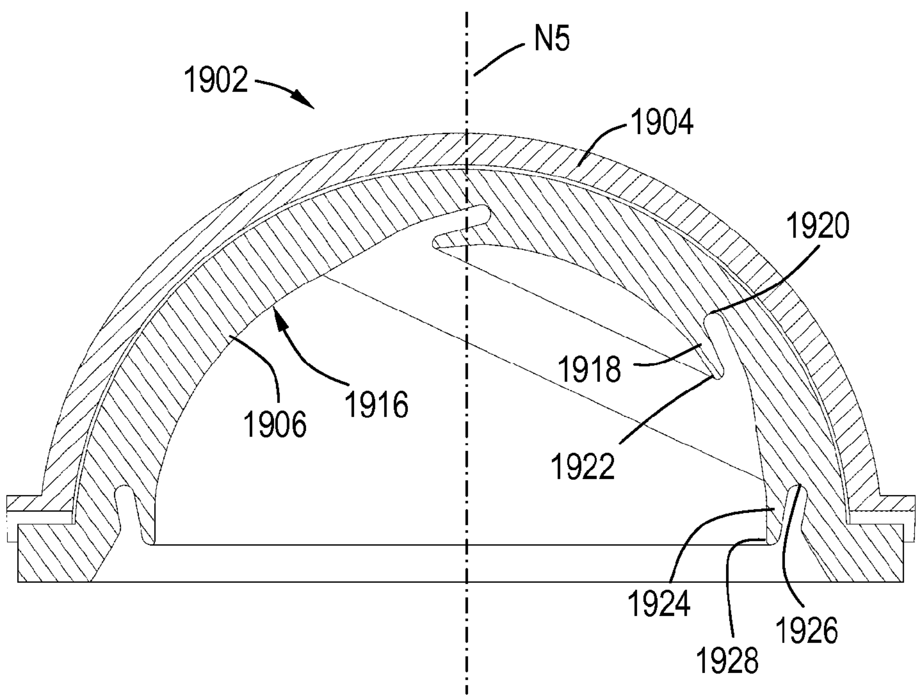

N5
1902
1904
1920
1918
1906
1916
1922
1924
1928
1926

FIG. 56

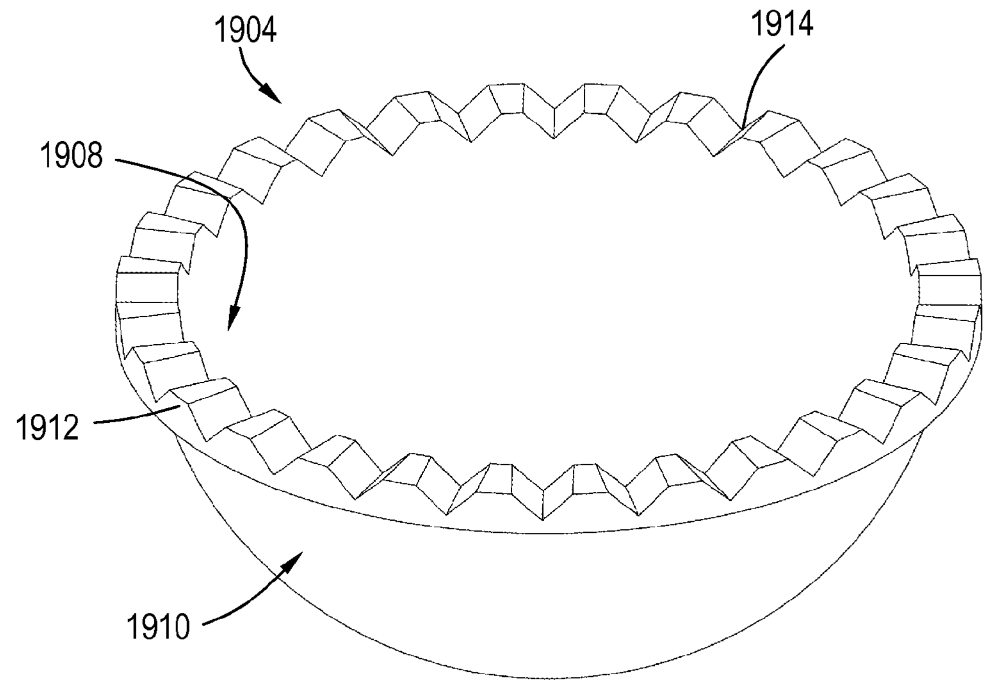


FIG. 57

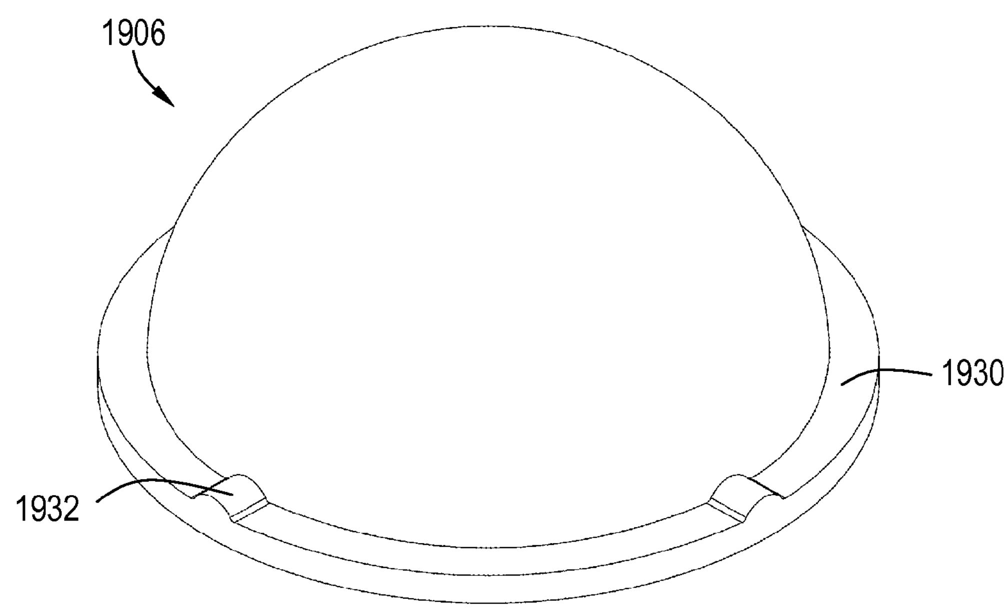
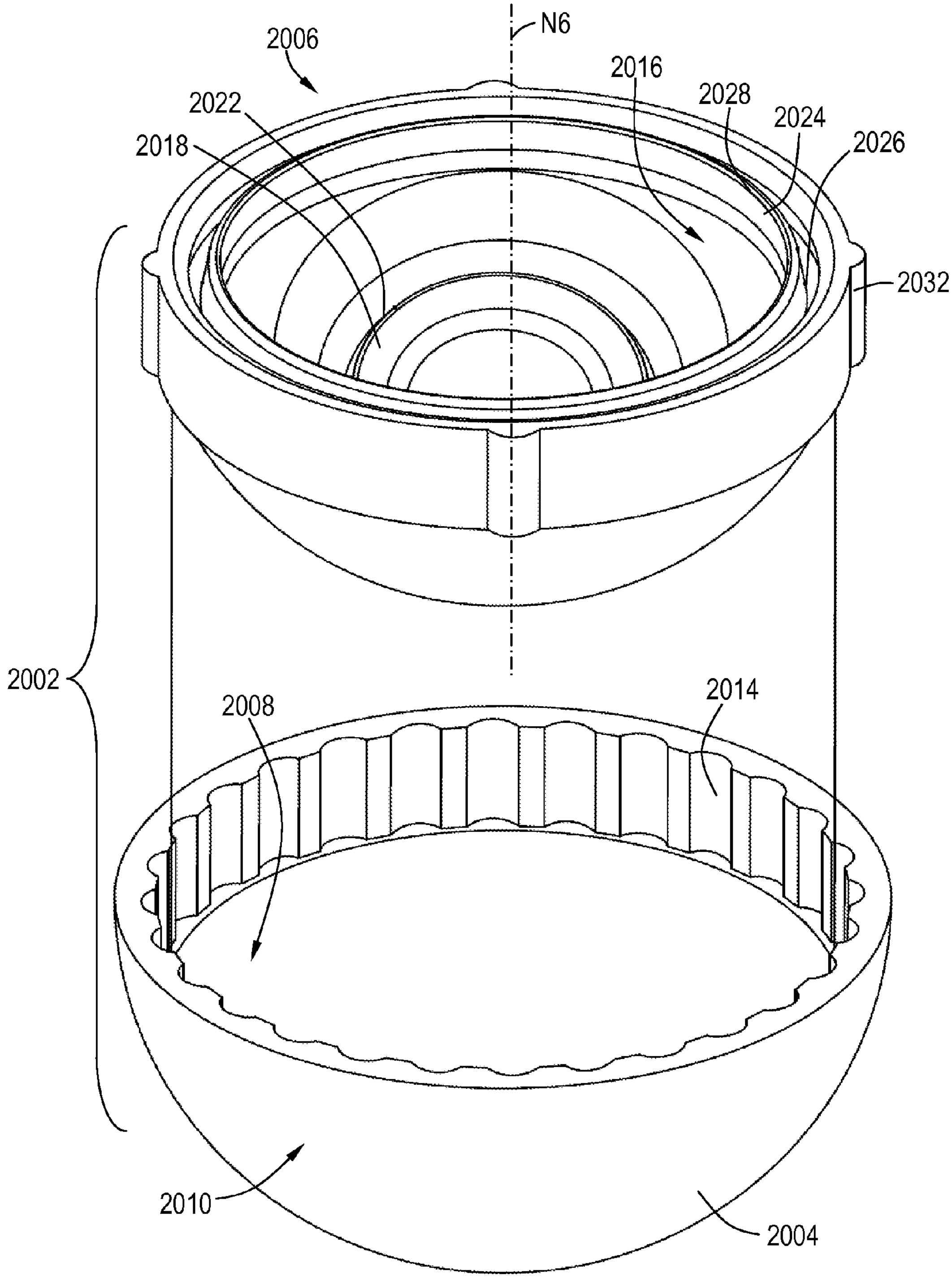
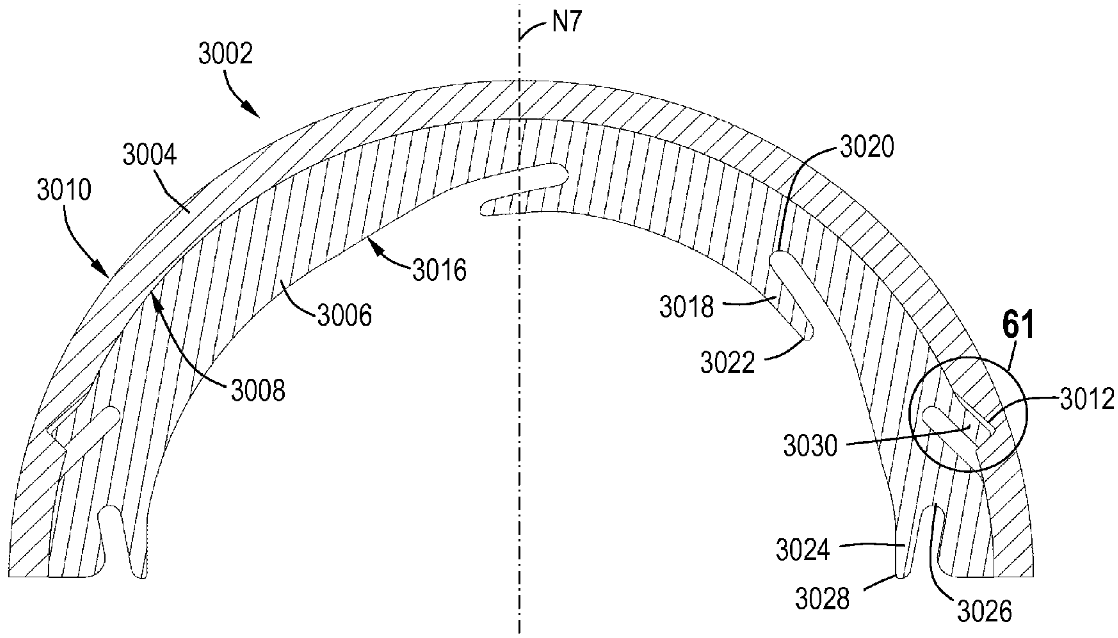


FIG. 58



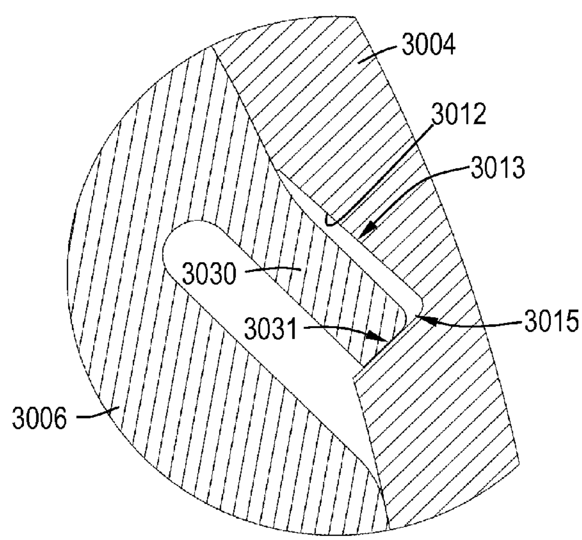
N6
2006
2016
2028
2024
2026
2022
2018
2032
2002
2008
2014
2010
2004

FIG. 59



N7
3002
3004
3010
3020
3016
3006
3018
3008
3022
61
3012
3030
3024
3028
3026

FIG. 60



3004
3012
3013
3030
3015
3031
3006

FIG. 61

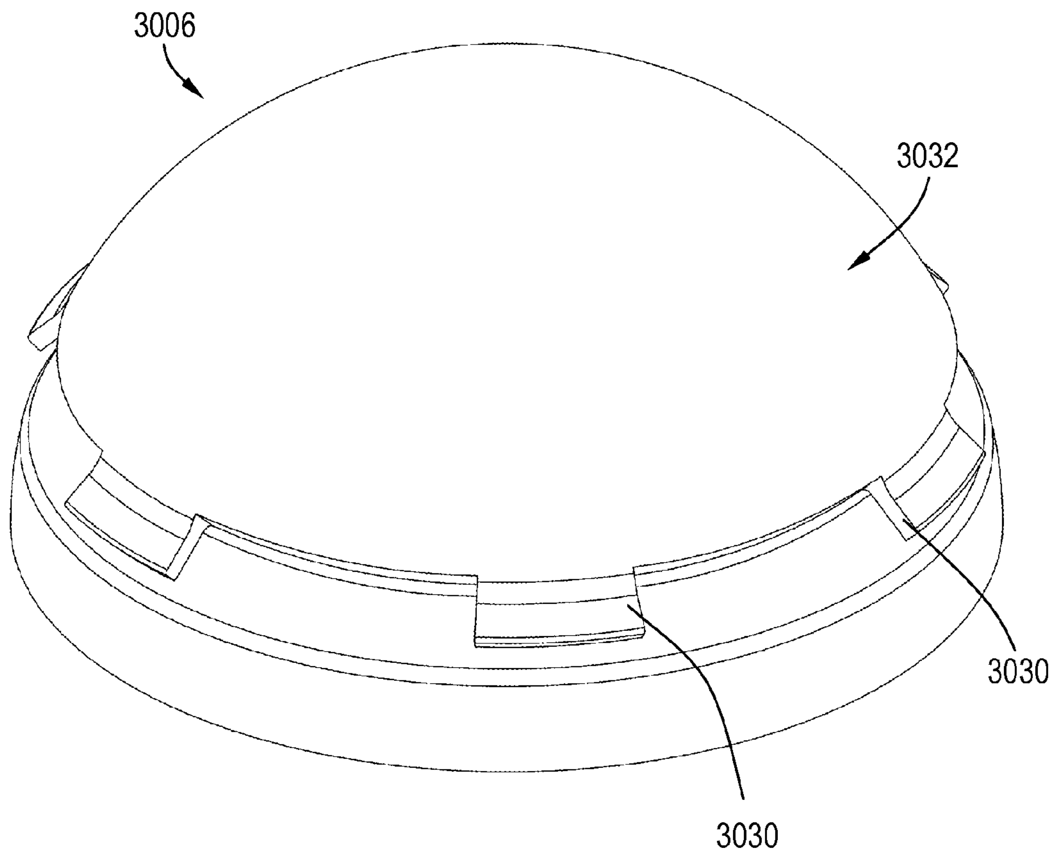


FIG. 62

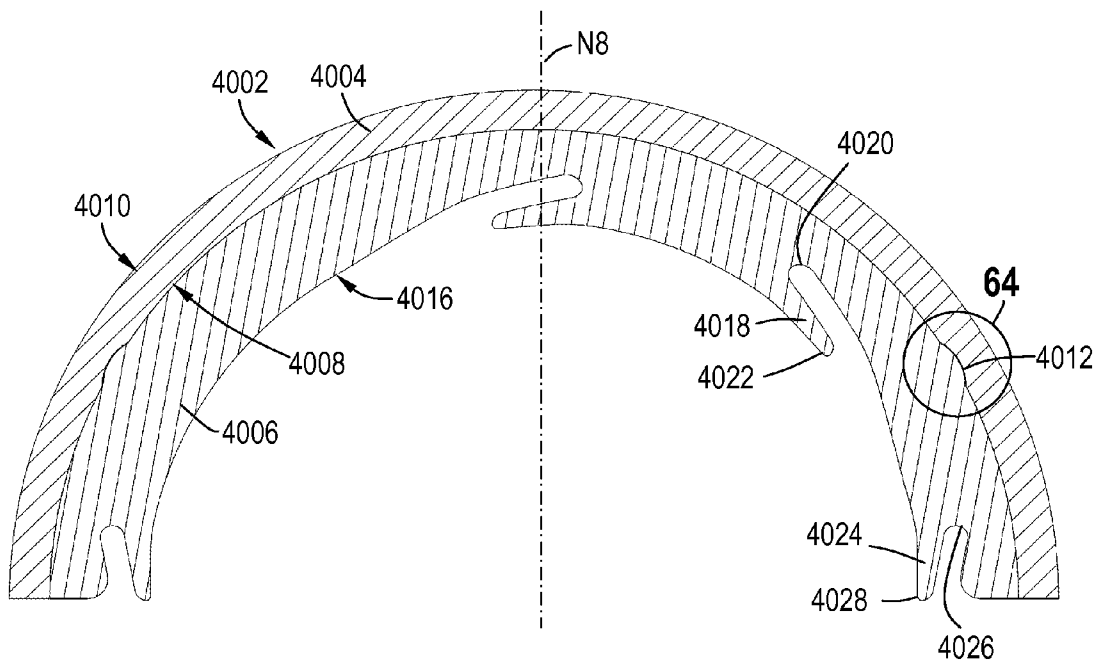

N8
4002
4004
4020
4010
64
4016
4018
4012
4008
4022
4006
4024
4028
4026

FIG. 63

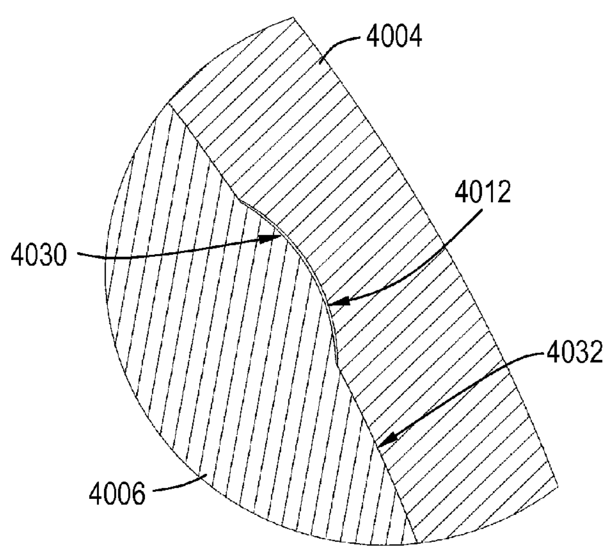
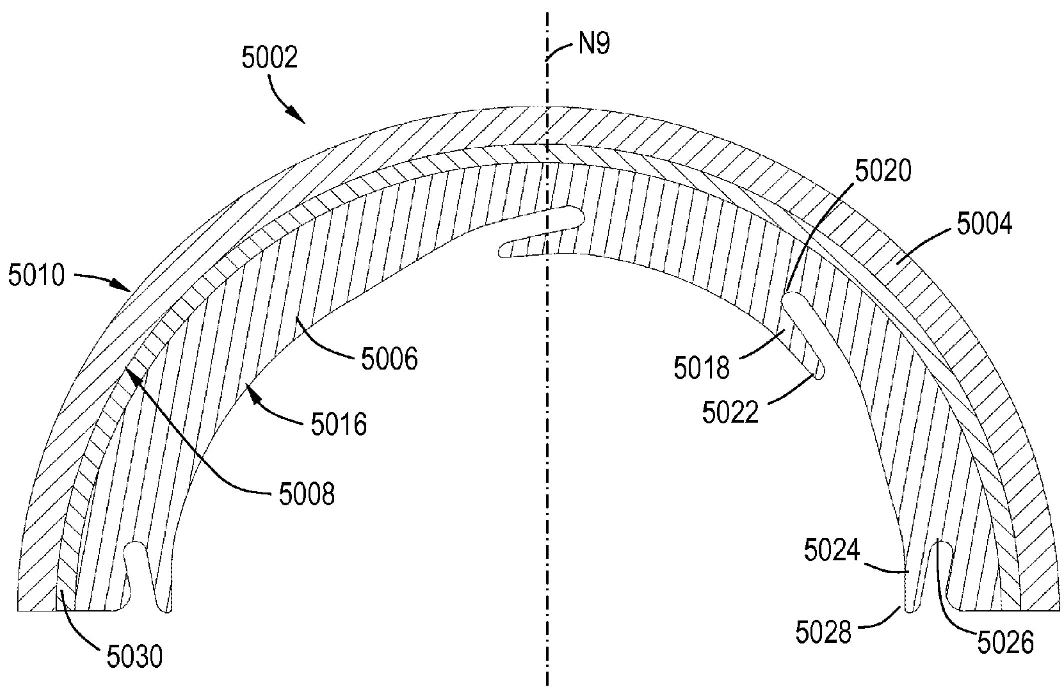
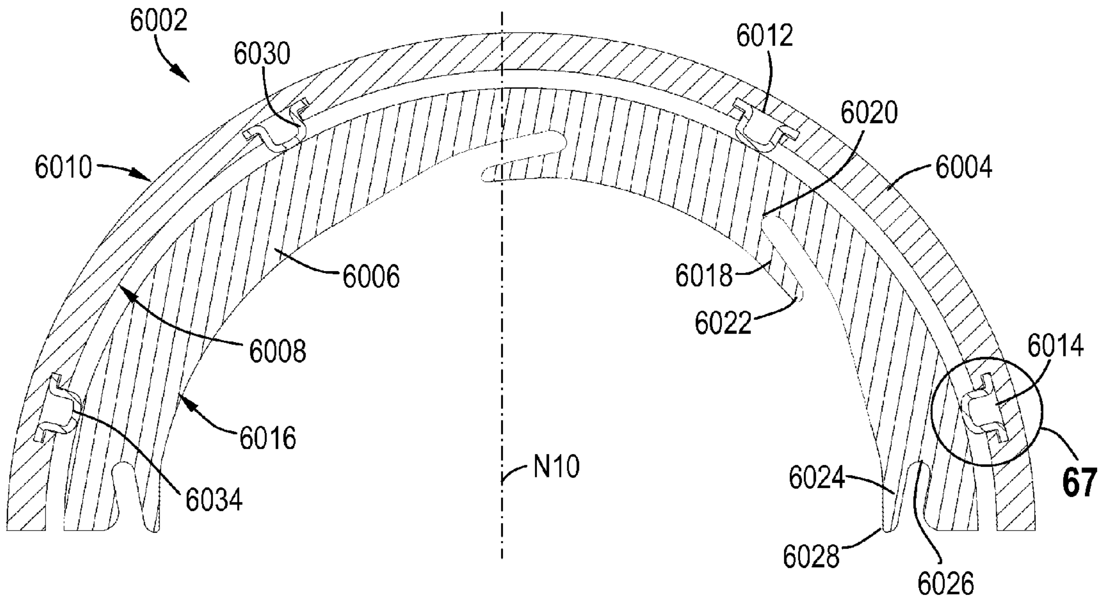

4004
4012
4030
4032
4006

FIG. 64



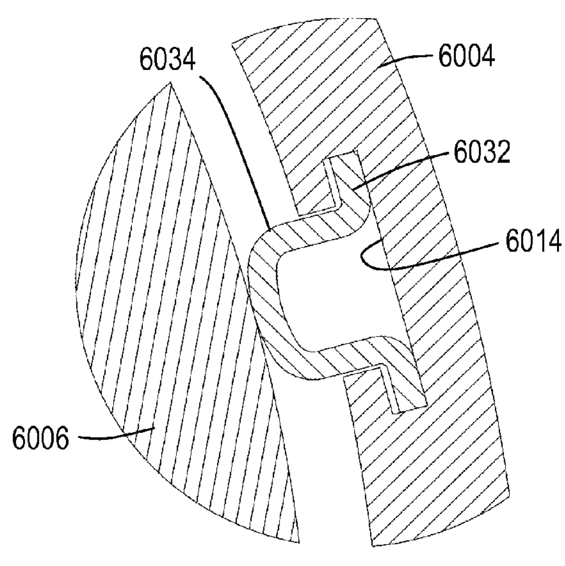
N9
5002
5020
5004
5010
5006
5018
5022
5016
5008
5024
5030
5028
5026

FIG. 65



6002
6030
6012
6020
6004
6010
6006
6018
6022
6008
6014
6016
N10
6034
6024
67
6028
6026

FIG. 66



6034
6004
6032
6014
6006

FIG. 67

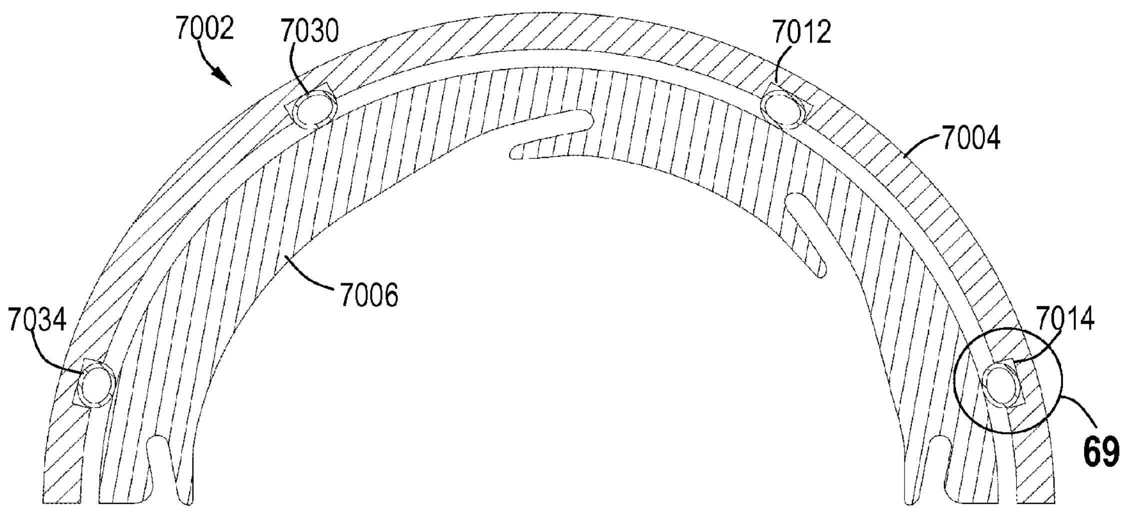


FIG. 68

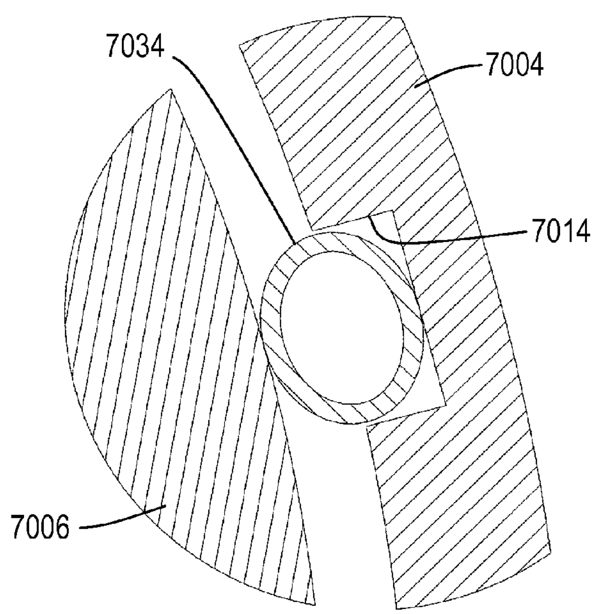


FIG. 69

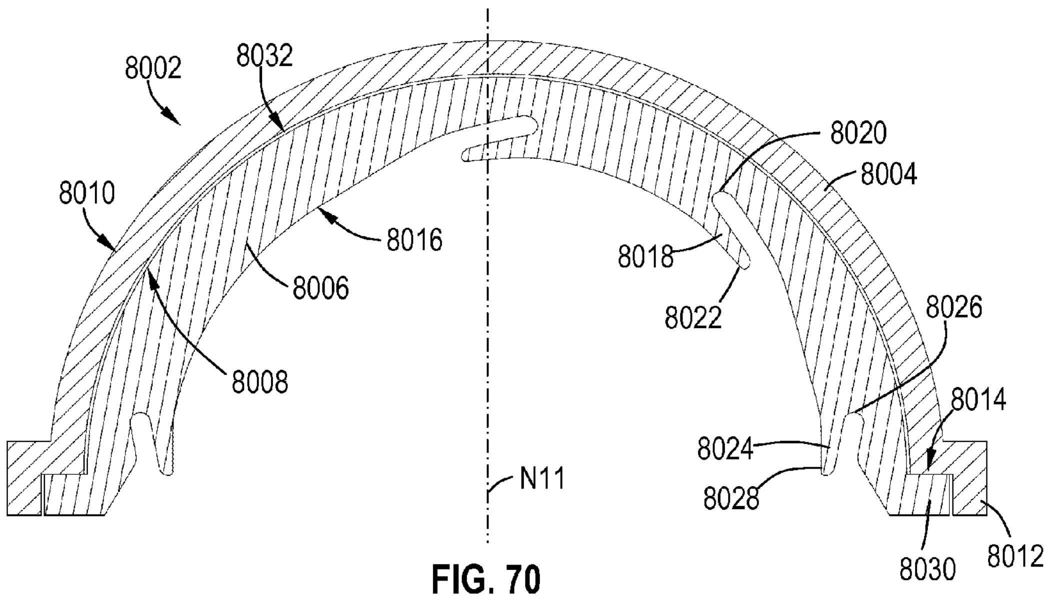

8002
8032
8020
8004
8010
8016
8018
8006
8022
8026
8008
8014
8024
N11
8028
8030
8012

FIG. 70

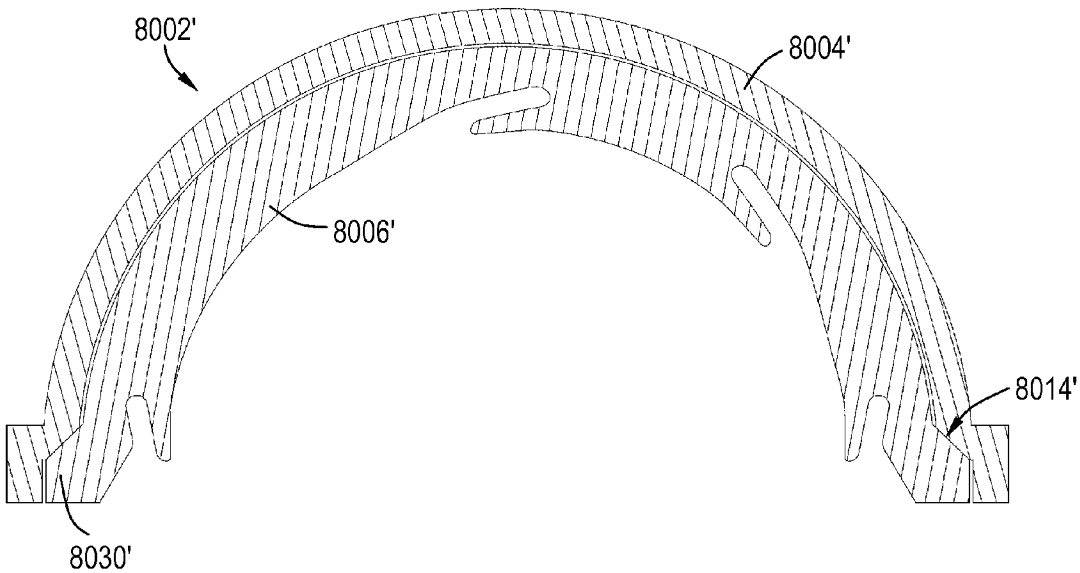

8002'
8004'
8006'
8014'
8030'

FIG. 71

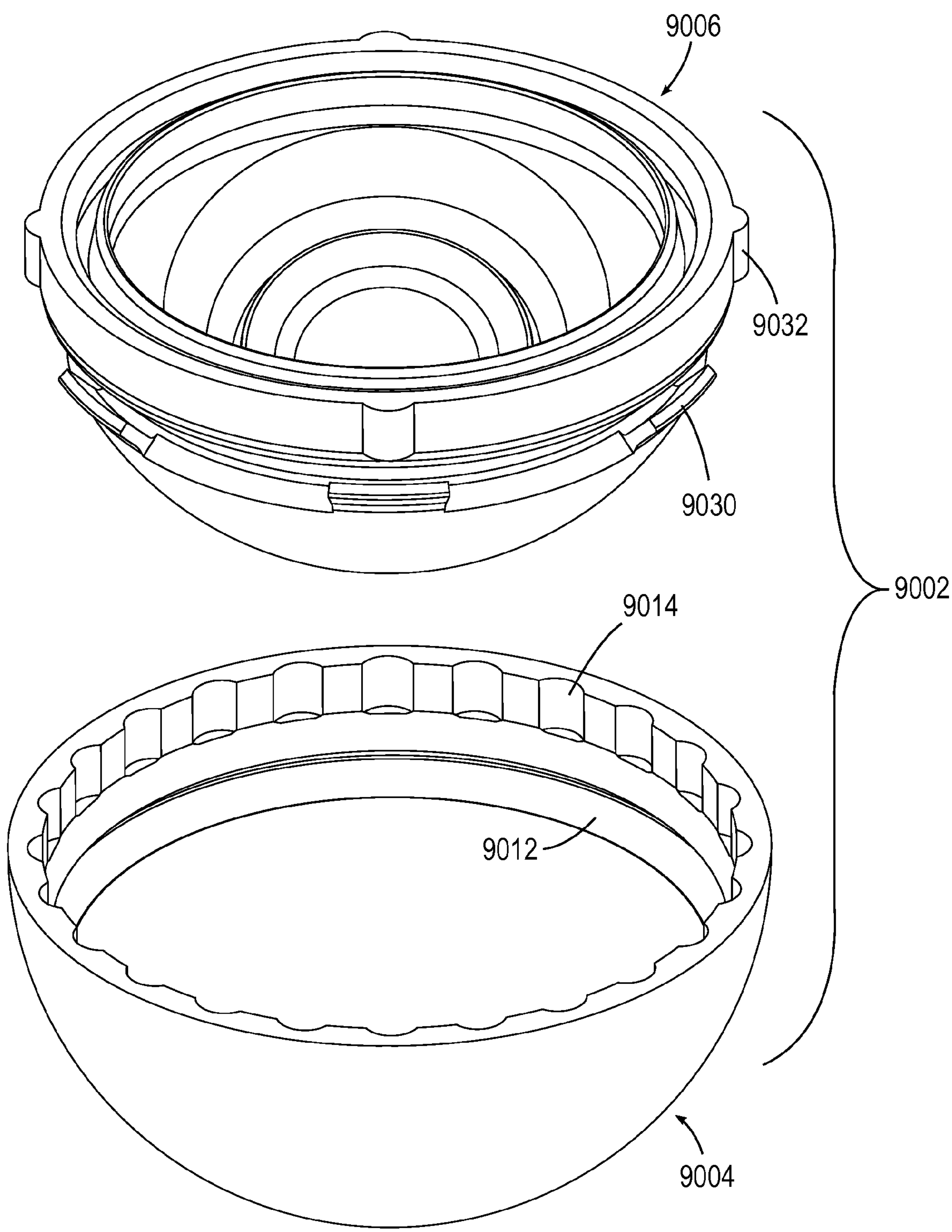


FIG. 72

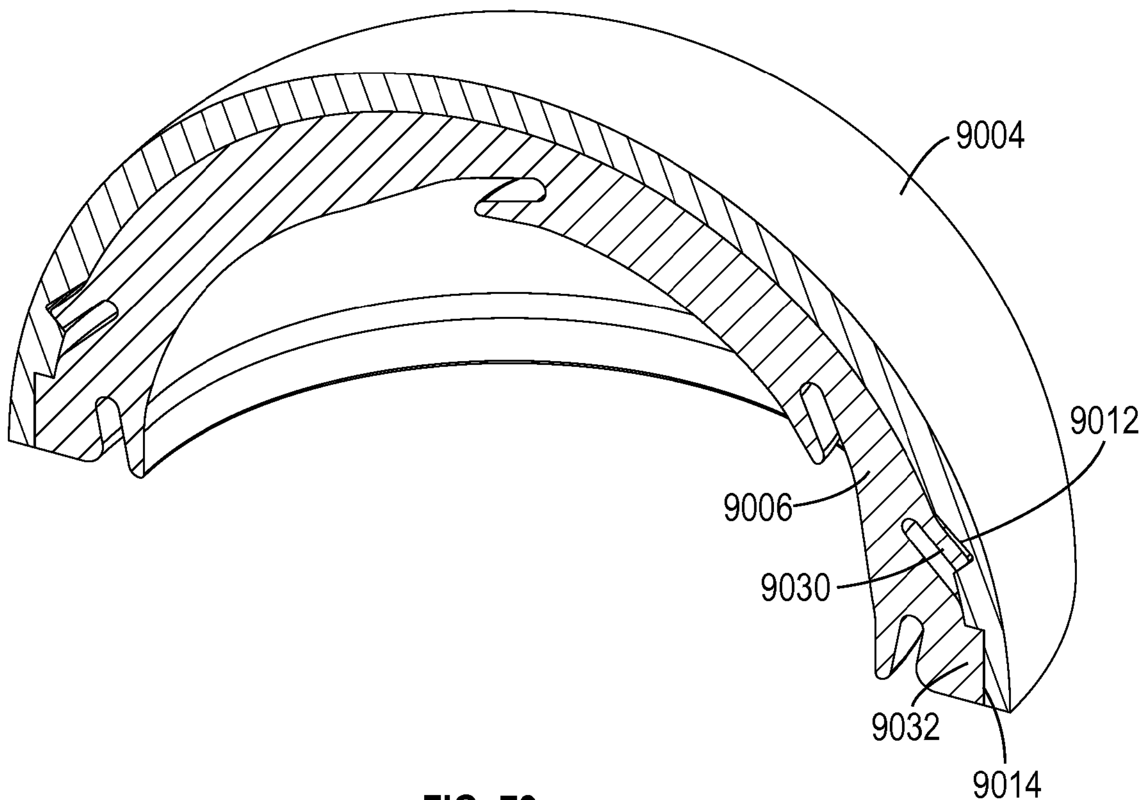


FIG. 73

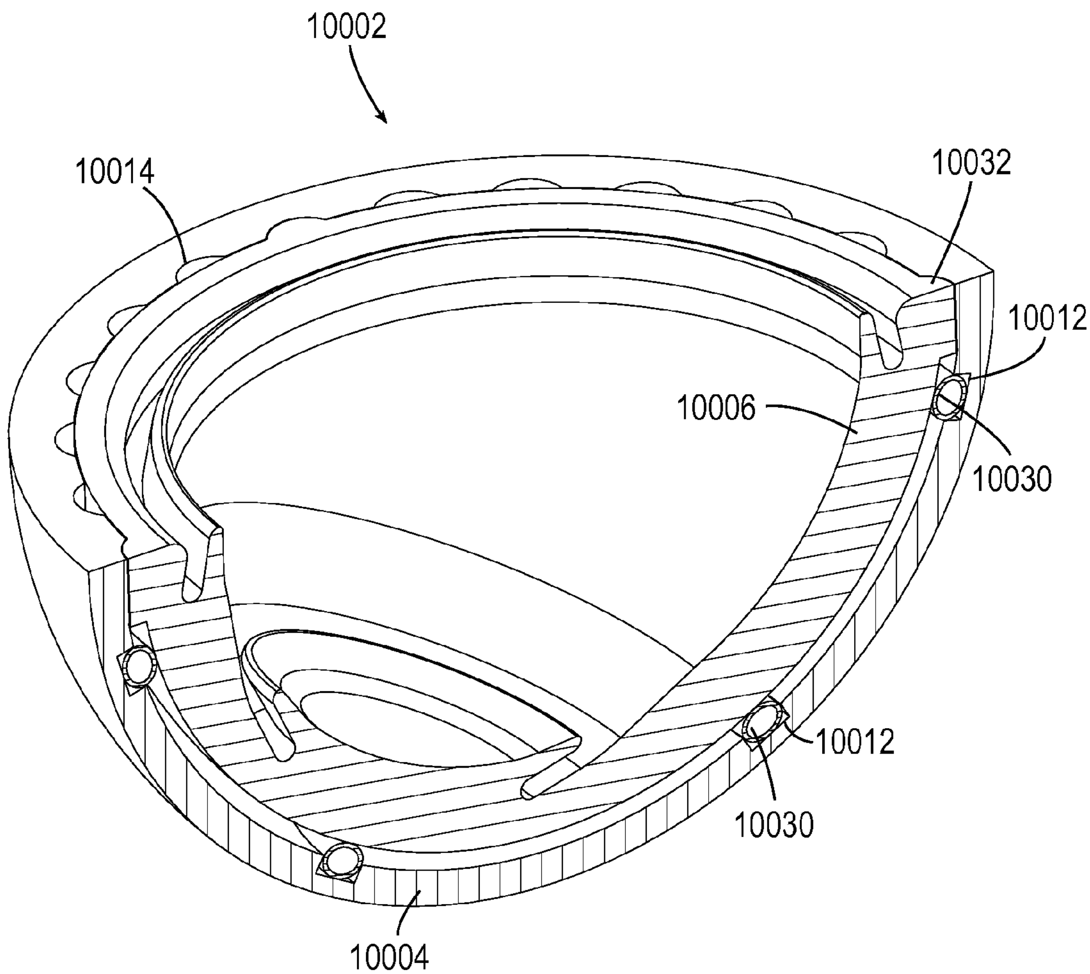


FIG. 74

PROSTHETIC JOINT ASSEMBLY AND PROSTHETIC JOINT MEMBER

BACKGROUND OF THE INVENTION

This invention relates generally to medical implants, and more particularly to prosthetic joints having conformal geometries and wear resistant properties.

Medical implants, such as knee, hip, and spine orthopedic replacement joints and other joints and implants have previously consisted primarily of a hard metal motion element that engages a polymer contact pad. This has usually been a high density high wear resistant polymer, for example Ultra-High Molecular Weight Polyethylene (UHMWPE), or other resilient material. The problem with this type of configuration is the polymer eventually begins to degrade due to the caustic nature of blood, the high impact load, and high number of load cycles. As the resilient member degrades, pieces of polymer may be liberated into the joint area, often causing accelerated wear, implant damage, and tissue inflammation and harm.

It is desirable to employ a design using a hard member on a hard member (e.g. metals or ceramics), thus eliminating the polymer. Such a design is expected to have a longer service life. Extended implant life is important as it is now often required to revise or replace implants. Implant replacement is undesirable from a cost, inconvenience, patient health, and resource consumption standpoint.

Implants using two hard elements of conventional design will be, however, subject to rapid wear. First, a joint having one hard, rigid element on another will not be perfectly shaped to a nominal geometry. Such imperfections will result in points of high stress, thus causing localized wear. Furthermore, two hard elements would lack the resilient nature of a natural joint. Natural cartilage has a definite resilient property, absorbing shock and distributing periodic elevated loads. This in turn extends the life of a natural joint and reduces stress on neighboring support bone and tissue. If two rigid members are used, this ability to absorb the shock of an active lifestyle could be diminished. The rigid members would transmit the excessive shock to the implant to bone interface. Some cyclical load in these areas stimulates bone growth and strength; however, excessive loads or shock stress or impulse loading the bone-to-implant interface will result in localized bone mass loss, inflammation, and reduced support.

BRIEF SUMMARY OF THE INVENTION

These and other shortcomings of the prior art are addressed by the present invention, which provides a prosthetic joint having wear-resistant contacting surfaces with conformal properties.

According to one aspect of the invention, a prosthetic member includes: a cup with an outer surface that is bone-implantable, the cup including a first indexing feature; an insert disposed inside the cup, the insert comprising a rigid material and including a concave interior defining a nominal surface, the interior including a cantilevered flange defined by an undercut in the insert, the flange defining a wear-resistant first contact surface which protrudes inward relative to the nominal surface, the insert including a second indexing feature; wherein the first and second indexing features engage each other so as to retain the insert in a fixed angular orientation relative to the cup.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

FIG. **1** is a cross-sectional view of a portion of a resilient contact member constructed in accordance with the present invention;

FIG. **2** is an enlarged view of the contact member of FIG. **1** in contact with a mating joint member;

FIG. **3** is a side view of a resilient contact member in contact with a mating joint member;

FIG. **4** is a cross-sectional view of a cup for an implant according to an alternate embodiment of the invention;

FIG. **5** is an enlarged view of a portion of the cup of FIG. **4**;

FIG. **6** is a perspective view of a finite element model of a joint member;

FIG. **7** is a cross-sectional view of an implant joint including a flexible seal;

FIG. **8** is an enlarged view of a portion of FIG. **7**;

FIG. **9** is a side view of a prosthetic joint constructed in accordance with an aspect of the present invention;

FIG. **10** is a cross-sectional view of the prosthetic joint of FIG. **9** in an unloaded condition;

FIG. **11** is a cross-sectional view of one of the members of the prosthetic joint of FIG. **9**;

FIG. **12** is an enlarged view of a portion of FIG. **10**;

FIG. **13** is a cross-sectional view of the prosthetic joint of FIG. **9** in a loaded condition;

FIG. **14** is an enlarged view of a portion of FIG. **13**;

FIG. **15** is a cross-sectional view of an alternative joint member;

FIG. **16** is an enlarged view of a portion of FIG. **15**;

FIG. **17** is a cross-sectional view of another alternative joint member;

FIG. **18** is a cross-sectional view of another alternative joint member including a filler material;

FIG. **19** is a cross-sectional view of another alternative joint member including a wiper seal;

FIG. **20** is a cross-sectional view of another alternative prosthetic joint;

FIG. **21** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **22** is a cross-sectional view of a prosthetic joint constructed in accordance with yet another aspect of the present invention; and

FIG. **23** is a perspective view of a joint member having a grooved surface.

FIG. **24** is a exploded perspective view of two mating joint members;

FIG. **25** is a top plan view of one of the joint members shown in FIG. **24**;

FIG. **26** is a cross-sectional view of one of the joint members shown in FIG. **24**;

FIG. **27** is a contact stress plot of the joint member shown in FIG. **26**;

FIG. **28** is a perspective view of a rigid joint member used for comparison purposes;

FIG. **29** is a cross-sectional view of the joint member shown in FIG. **28**; and

FIG. **30** is a contact stress plot of the joint member shown in FIG. **29**;

FIG. **31** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **32** is an enlarged view of a portion of the joint shown in FIG. **31**;

FIG. **33** is a cross-sectional view of a cup member of the joint shown in FIG. **31**;

FIG. **34** is a greatly enlarged cross-sectional view of a portion of the joint shown in FIG. **31** in an initial condition;

FIG. **35** is a greatly enlarged cross-sectional view of a portion of the joint shown in FIG. **31** after an initial wear-in period;

FIG. **36** is a graph showing contact pressure of the joint of FIG. **31** compared to the number of operating cycles;

FIG. **37** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **38** is an enlarged view of a portion of the joint shown in FIG. **37**;

FIG. **39** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **40** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **41** is a plan view of a portion of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **42** is a view taken along lines **42-42** of FIG. **41**;

FIG. **43** is a view taken along lines **43-43** of FIG. **41**;

FIG. **44** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **45** is a perspective view of the prosthetic joint of FIG. **44**;

FIG. **46** is a perspective view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **47** is a cross-sectional view of the prosthetic joint of FIG. **46**;

FIG. **48** is a sectional perspective view of a prosthetic joint constructed in accordance with another aspect of the present invention;

FIG. **49** is an enlarged portion of the joint of FIG. **48**, showing a rim configuration thereof;

FIG. **50** is a sectional perspective view showing an alternative rim configuration for use with the joint shown in FIG. **49**;

FIG. **51** is a sectional perspective view showing another alternative rim configuration for use with the joint shown in FIG. **49**;

FIG. **52** is a sectional perspective view of a member of a prosthetic joint with an aperture formed therein;

FIG. **53** is a cross-sectional view of a prosthetic joint showing a multi-piece construction;

FIG. **54** is a cross-sectional view of a prosthetic joint constructed in accordance with another aspect of the present invention

FIG. **55** is a perspective view of a prosthetic joint member;

FIG. **56** is a cross-sectional view of the joint member of FIG. **55**;

FIG. **57** is a perspective view of a cup of the joint member of FIG. **55**;

FIG. **58** is a perspective view of an insert of the joint member of FIG. **55**;

FIG. **59** is an exploded perspective view of a prosthetic joint member;

FIG. **60** is a cross-sectional view of a prosthetic joint member;

FIG. **61** is an enlarged view of a portion of the joint member of FIG. **60**;

FIG. **62** is a perspective view of an insert of the joint member of FIG. **60**;

FIG. **63** is a cross-sectional view of a prosthetic joint member;

FIG. **64** is an enlarged view of a portion of the joint member of FIG. **63**;

FIG. **65** is a cross-sectional view of a prosthetic joint member;

FIG. **66** is a cross-sectional view of a prosthetic joint member;

FIG. **67** is an enlarged view of a portion of the joint member of FIG. **66**;

FIG. **68** is a cross-sectional view of a prosthetic joint member;

FIG. **69** is an enlarged view of a portion of the joint member of FIG. **68**;

FIG. **70** is a cross-sectional view of a prosthetic joint member;

FIG. **71** is a cross-sectional view of a prosthetic joint member;

FIG. **72** is an exploded perspective view of a prosthetic joint;

FIG. **73** is a perspective cross-sectional view of the prosthetic joint of FIG. **72**; and

FIG. **74** is a perspective cross-sectional view of a prosthetic joint.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a specialized implant contact interface (implant geometry). In this geometry, an implanted joint includes two typically hard (i.e. metal or ceramic) members; however, at least one of the members is formed such that it has the characteristics of a resilient member, such as: the ability to absorb an impact load; the ability to absorb high cycle loading; the ability to be self cleaning; and the ability to function as a hydrodynamic and/or hydrostatic bearing.

Generally, the contact resilient member is flexible enough to allow elastic deformation and avoid localized load increases, but not so flexible as to risk plastic deformation, cracking and failure. In particular, the resilient member is designed such that the stress levels therein will be below the high-cycle fatigue endurance limit. As an example, the resilient member might be only about 10% to about 20% as stiff as a comparable solid member. It is also possible to construct the resilient member geometry with a variable stiffness, i.e. having a low effective spring rate for small deflections and a higher rate as the deflections increase, to avoid failure under sudden heavy loads.

FIG. **1** illustrates an exemplary contact member **34** including a basic resilient interface geometry. The contact member **34** is representative of a portion of a medical implant and is made of one or more metals or ceramics (for example, partially stabilized Zirconia). It may be coated as described below. The geometry includes a lead-in shape, Z**1** and Z**2**, a contact shape, Z**3** and Z**4**, a lead-out shape, Z**5** and Z**6**, and a relieved shape, Z**7**. It may be desired to vary the cross-sectional thickness to achieve a desired mechanical stiffness to substrate resilience characteristic. The presence of the relieved region Z**7** introduces flexibility into the contact member **34**, reduces the potential for concentrated point contact with a mating curved member, and provides a reservoir for a working fluid.

The Z**7** region may be local to the contact member **34** or may be one of several. In any case, it may contain a means of providing fluid pressure to the internal contact cavity to produce a hydrostatic interface. A passive (powered by the regular motion of the patient) or active (powered by micro components and a dedicated subsystem) pumping means and optional filtration may be employed to provide the desired fluid interaction.

A hydrodynamic interface is desirable as, by definition, it means the contact member **34** is not actually touching the mating joint member. The lead-in and lead-out shapes Z**1**, Z**2**, Z**5**, Z**6** are configured to generate a shear stress in the working fluid so as to create the fluid "wedge" of a hydrodynamic support.

FIG. **2** shows a closer view of the contact member **34**. It may be desirable to make the contact radius (Z**3** and Z**4**) larger or smaller, depending on the application requirement and flexural requirement. For example, FIG. **3** illustrates the contact member **34** in contact with a mating joint member **38** having a substantially larger radius than the contact member **34**. The radius ratio between the two joint members is not particularly critical, so long as one of the members exhibits the resilient properties described herein.

The contact member **34** includes an osseointegration surface "S", which is a surface designed to be infiltrated by bone growth to improve the connection between the implant and the bone. Osseointegration surfaces may be made from materials such as TRABECULAR METAL, textured metal, or sintered or extruded implant integration textures. TRABECULAR METAL is an open metal structure with a high porosity (e.g. about 80%) and is available from Zimmer, Inc., Warsaw, Ind. 46580 USA.

FIGS. **4** and **5** illustrate a cup **48** of metal or ceramic with two integrally-formed contact rings **50**. More contact rings may be added if needed. As shown in FIG. **5**, the volume behind the contact rings **50** may be relieved. This relieved area **52** may be shaped so as to produce a desired balance between resilience and stiffness. A varying cross-section geometry defined by varying inner and outer spline shapes may be desired. In other words, a constant thickness is not required. A material such as a gel or non-Newtonian fluid (not shown) may be disposed in the relieved area **52** to modify the stiffness and damping characteristics of the contact rings **50** as needed for a particular application. The cup **48** could be used as a stand-alone portion of a joint, or it could be positioned as a liner within a conventional liner. The contact ring **50** is shown under load in FIG. **6**, which depicts contour lines of highest compressive stress at "C**1**". This is the portion of the contact ring **50** that would be expected to undergo bending first. The bearing interface portion of the resilient contact member could be constructed as a bridge cross-section supported on both sides as shown or as a cantilevered cross-section depending on the desired static and dynamic characteristics.

FIGS. **7** and **8** illustrate an implant **56** of rigid material which includes a wiper seal **58**. The wiper seal **58** keeps particles out of the contact area (seal void) **60** of the implant **58**, and working fluid (natural or synthetic) in. The seal geometry is intended to be representative and a variety of seal characteristics may be employed; such as a single lip seal, a double or multiple lip seal, a pad or wiper seal made from a variety of material options. Different seal mounting options may be used, for example a lobe in a shaped groove as shown in FIGS. **7** and **8**, a retaining ring or clamp, or an adhesive. The wiper seal **58** may also be integrated into the contact face of the interface zone.

It may be desirable to create a return passage **62** from the seal void region **60** back into the internal zone **64** in order to stabilize the pressure between the two and to allow for retention of the internal zone fluid if desired. This is especially relevant when the hydrostatic configuration is considered.

FIGS. **9-14** illustrate a prosthetic joint **100** comprising first and second members **102** and **104**. The illustrated prosthetic joint **100** is particularly adapted for a spinal application, but it will be understood that the principles described herein may be applied to any type of prosthetic joint. Both of the members **102** and **104** may be bone-implantable, meaning they include osseointegration surfaces, labeled "S", which are surfaces designed to be infiltrated by bone growth to improve the connection between the implant and the bone. Osseointegration surfaces may be made from materials such as TRABECULAR METAL, textured metal, or sintered or extruded implant integration textures, as described above. As shown in FIG. **10**, a central axis "A" passes through the centers of the first and second members **102** and **104** and is generally representative of the direction in which external loads are applied to the joint **100** in use. In the illustrated examples, the first and second joint members are bodies of revolution about this axis, but the principles of the present invention also extend to shapes that are not bodies of revolution.

The first member **102** includes a body **106** with a perimeter flange **116** extending in a generally radially outward direction at one end. Optionally, a disk-like base **108** may be disposed at the end of the body **106** opposite the flange **116**, in which case a circumferential gap **111** will be defined between the base **106** and the flange **116**. The first member **102** is constructed from a rigid material. As used here, the term "rigid" refers to a material which has a high stiffness or modulus of elasticity. Nonlimiting examples of rigid materials having appropriate stiffness for the purpose of the present invention include stainless steels, cobalt-chrome alloys, titanium, aluminum, and ceramics. By way of further example, materials such as polymers would generally not be considered "rigid" for the purposes of the present invention. Generally, a rigid material should have a modulus of elasticity of about 0.5×10^6 psi or greater. Collectively, one end of the body **106** and the flange **116** define a wear-resistant, concave first contact surface **118**. As used herein, the term "wear-resistant" refers to a material which is resistant to surface material loss when placed under load. Generally the wear rate should be no more than about 0.5 μm (0.000020 in.) to about 1.0 μm (0.000040 in.) per million cycles when tested in accordance with ASTM Guide F2423. As a point of reference, it is noted that any of the natural joints in a human body can easily experience one million operating cycles per year. Nonlimiting examples of wear-resistant materials include solid metals and ceramics. Known coatings such as titanium nitride, chrome plating, carbon thin films, and/or diamond-like carbon coatings may be used as a face layer to impart wear resistance to the first contact surface **118**. Optionally, the first contact surface **118** could comprise a substantially thicker face layer (not shown) of a wear-resistant material such as ultra-high molecular weight (UHMW) polyethylene.

The first contact surface **118** includes a protruding peripheral rim **120** (see FIG. **11**), and a recessed central portion **122**, which may also be considered a "pocket" or a "relief". As used herein, the term "recessed" as applied to the central portion **122** means that the central portion **122** lies outside of the nominal exterior surface of the second member **104** when the joint **100** is assembled. The terms "recessed" and "protruding" as used herein are opposite in meaning to one another. For example, the peripheral rim **120** protrudes relative to a nominal surface defined by the central portion **122**, and the central portion **122** is recessed relative to the rim **120**. In one configuration, shown in FIGS. **9-14**, and best seen in FIG. **11**, the rim **120** is concave, with the radius of curvature being quite high, such that the cross-sectional shape of the surface of the rim **120** approaches a straight line. FIGS. **15** and **16** show another configuration of a joint member **102'** with a flange **116'** in which the rim **120'** has a convex-curved cross-sectional shape. The cross-sectional shape of the rim may be flat or curved as necessary to suit a particular application.

The annular configuration of first contact surface **118** with the protruding rim **120** results in a configuration which permits only pivoting and rotational motion, and is statically and dynamically determinate for the life of the joint **100**. In contrast, prior art designs employing mating spherical shapes, even very accurate shapes, quickly reach a statically and dynamically indeterminate condition after use and wear. This condition accelerates wear, contributes to the fretting corrosion wear mechanism, and permits undesired lateral translation between the joint members.

The second member **104** is also made from a rigid material and has a wear-resistant, convex second contact surface **124**. The first and second contact surfaces **118** and **124** bear directly against each other so as to transfer axial and lateral loads from one member to the other while allowing pivoting motion between the two members **102** and **104**.

Nominally the first and second members **102** and **104** define a "ring" or "band" contact interface therebetween. In practice it is impossible to achieve surface profiles completely free of minor imperfections and variations. If the first and second members **102** and **104** were both completely rigid, this would cause high Hertzian contact stresses and rapid wear. Accordingly, an important feature of the illustrated joint **100** is that the flange **116** (and thus the first contact surface **118**) of the first member **102** is conformable to the second contact surface **124** when the joint is placed under load.

FIGS. **10** and **12** show a cross-sectional view of the flange **116** in an unloaded condition or free shape. It can be seen that the distal end of the rim **120** contacts the second contact surface **124**, while the inboard end of the rim **120** (i.e. near where the flange **116** joins the body **106**) does not. FIGS. **13** and **14** show the flange **116** in a deflected position or loaded shape, where substantially the entire section width of the rim **120** contacts the second contact surface **124**, resulting in a substantially increased contact surface area between the two members **102** and **104**, relative to the free shape. The rim **120'** of the joint member **102'** (see FIG. **16**) is similarly conformable; however, given the curved cross-sectional shape, the total amount of surface contact area remains substantially constant in both loaded and unloaded conditions, with the rim **120'** undergoing a "rolling" or "rocking" motion as the loading changes.

The conformable nature of the flange **116** is explained in more detail with reference to FIGS. **24** through **30**. As noted above, the first member **102** has a flange **116** and a concave first contact surface **118**. The second member **104** has a convex second contact surface **124**. When assembled and in use the joint **100** is subject, among other loads, to axial loading in the direction of the arrows labeled "F" in FIG. **24** (i.e. along axis "A" of FIG. **10**). As previously stated, it is impossible in practice for either of the contact surfaces **118** or **124** to be perfect surfaces (i.e. a perfect sphere or other curve or collection of curves). It is believed that in most cases that a defect such as a protrusion from the nominal contact surface of just 0.00127 mm (0.00005 in.), that is, 50 millionths of an inch, or larger, would be sufficient to cause fretting corrosion and failure of a metal-on-metal joint constructed to prior art standards. A defect may include a variance from a nominal surface shape as well as a discontinuity in the contact surface. Defects may arise through a variety of sources such as manufacturing, installation, and/or operating loads in the implanted joint.

FIG. **25** shows the second member **104** which in this particular example varies from a nominal shape in that it is elliptical rather than circular in plan view. The elliptical shape is grossly exaggerated for illustrative purposes. For reference, the dimensions of the second member **104** along the major axis labeled "X" is about 0.0064 mm (0.00025 in.) larger than its dimension along the minor axis labeled "Y". When assembled and loaded, the flange **116** conforms to the imperfect second contact surface **124** and deflects in an irregular shape. In other words, in addition to any uniform deflection which may be present, the deflected shape of the flange **116** includes one or more specific locations or portions that are deflected towards or away from the nominal free shape to a greater or lesser degree than the remainder of the flange **116**. Most typically the deflected shape would be expected to be non-axisymmetric. For example, the deflection of the flange **116** at points located at approximately the three o'clock and nine o' clock positions is substantially greater than the deflection of the remainder of the flange **116**. As a result, the contact stress in that portion of the first contact surface **118** is relieved. FIG. **27** is a plan view plot (the orientation of which is shown by arrow in FIG. **26**) which graphically illustrates the expected contact stresses in the first contact surface **118** as determined by analytical methods. The first contour line "C**2**" shows that a very low level of contract stress is present around the entire perimeter of the first contact surface **118**. This is because the entire first contact surface **118** is in contact with the second contact surface **124**. Another contour line "C**3**" represents the areas of maximum contact stress corresponding to the protruding portions of the elliptical second contact surface **124**.

For comparative purposes, FIGS. **28** and **29** depict a member **902** constructed according to prior art principles. The member **902** has a contact surface **918** with an identical profile and dimensions of the first contact surface **118** of the first member **102**. However, consistent with the prior art, the member **902** has a massive body **920** behind the entire contact surface **918**, rendering the entire member **902** substantially rigid. FIG. **30** graphically illustrates the expected contact stresses in the contact surface **918** as determined by analytical methods, when the member **902** is assembled and placed in contact with the second member **104**, using the same applied load as depicted in FIG. **27**. Because of the rigidity of the member **902**, a "bridging" effect is present wherein contact between the contact surfaces (one of which is circular in plan view, and the other of which is elliptical) effectively occurs at only two points, located at approximately the three o'clock and nine o' clock positions. A first contour line "C**4**" shows two discrete areas where the lowest level of contract stress is present. These lines are not contiguous because there is no contact in the remaining area of the contact surfaces (for example at the six o'clock and twelve o'clock positions). Another contour line "C**5**" represents the areas of maximum contact stress. Analysis shows a peak contact stress having a magnitude of two to twenty times (or more) the peak contact stress of the inventive joint as shown in FIG. **27**.

To achieve this controlled deflection, the flange **116** is thin enough to permit bending under working loads, but not so thin as to allow material yield or fatigue cracking. The deflection is opposed by the elasticity of the flange **116** in bending, as well as the hoop stresses in the flange **116**. To achieve long life, the first member **102** is sized so that stresses in the flange **116** will be less than the endurance limit of the material, when a selected external load is applied. In this particular example, the joint **100** is intended for use between two spinal vertebrae, and the design average axial working load is in the range of about 0 N (0 lbs.) to about 1300 N (300 lbs.). These design working loads are derived from FDA-referenced ASTM and ISO standards for spinal disc prostheses. In this example, the thickness of the flange **116**, at a root **126** where it joins the body **106** (see FIG. **12**) is about 0.4 mm (0.015 in.) to about 5.1 mm (0.200 in.), where the outside diameter of the flange **116** is about 6.4 mm (0.25 in.) to about 7.6 cm (3.0 in.).

The joint members may include multiple rims. For example, FIG. **17** illustrates a joint member **202** where the first contact surface **218** includes two protruding rims **220**, with a circumferential groove or relief area **228** therebetween. The presence of multiple rims increases the contact surface areas between the two joint members.

If present, the circumferential gap between the flange and the base of the joint member may be filled with resilient nonmetallic material to provide damping and/or additional spring restoring force to the flange. FIG. **18** illustrates a joint member **302** with a filler **304** of this type. Examples of suitable resilient materials include polymers, natural or synthetic rubbers, and the like.

As discussed above, the joint may incorporate a wiper seal. For example, FIG. **19** illustrates a joint member **402** with a resilient wiper seal **404** protruding from the rim **420** of the first contact surface **418**. The wiper seal **404** keeps particles out of the contact area (seal void), while containing working fluid (natural or synthetic). The seal geometry is intended to be representative and a variety of seal characteristics may be employed; such as a single lip seal, a double or multiple lip seal. A pad or wiper seal may be made from a variety of material options. Different seal mounting options may be used, for example a lobe in shaped groove as shown in FIG. **18**, a retaining ring or clamp, adhesion substance. The seal may also be incorporated into the contact face of the interface zone.

The joint construction described above can be extended into a three-part configuration. For example, FIG. **20** illustrates a prosthetic joint **500** having first, second, and third members **502**, **504**, and **506**. The first and second members **502** and **504** are similar in construction to the first member **102** described above, and each includes a body **508**, an optional disk-like base **510**, and a flange **512**. The flanges **512** define wear-resistant concave first and second contact surfaces **514** and **516**, each of which includes a protruding peripheral rim, and a recessed central portion as described above. The third member **506** has a double-convex shape defining opposed wear-resistant, convex third and fourth contact surfaces **524** and **526**. The first and second **514** and **516** bear against the third and fourth contact surfaces **524** and **526**, respectively, so as to transfer axial (i.e. compression) and lateral loads between the first and second members **502** and **504** through the third member **506**, while allowing pivoting motion between the members **502**, **504**, and **506**. The first and second contact surfaces **514** and **516** are conformal to the third and fourth contact surfaces **524** and **526** as described in more detail above.

FIG. **21** illustrates an alternative prosthetic joint **600** comprising first and second members **602** and **604** constructed from rigid materials. Both of the members **602** and **604** may be bone-implantable, meaning they include osseointegration surfaces, labeled "S", as described in more detail above.

The first member **602** is hollow and includes a disk-like base **606** and a cup **608**, interconnected by a peripheral wall **610**. An interior cavity **612** is defined between the base **606** and the cup **608**. The cup **608** is constructed from a rigid material and defines a wear-resistant, concave first contact surface **614**. The first contact surface **614** includes a protruding peripheral rim **616**, and a recessed central portion **618**, which may also be considered a "pocket" or a "relief". The rim **616** may have a conical or curved cross-sectional shape. The interior cavity **612** may be filled with resilient nonmetallic material to provide damping and/or additional spring restoring force to the flange. Examples of suitable resilient materials include polymers, natural or synthetic rubbers, and the like.

The second member **604** is constructed from a rigid material and has a wear-resistant, convex second contact surface **620**. The first and second contact surfaces **614** and **616** bear directly against each other so as to transfer axial and lateral loads from one member to the other while allowing pivoting motion between the two members **602** and **604**.

As described above with reference to the prosthetic joint **100**, the cup **606** of the first member **602** is thin enough to permit bending under working loads, but not so thin as to allow material yield or fatigue cracking. The first contact surface **614** is thus conformable to the second contact surface **620** when the prosthetic joint **600** is placed under external load.

An inverted configuration of hollow members is also possible. For example,

FIG. **22** illustrates a prosthetic joint **700** comprising first and second members **702** and **704**, both constructed of rigid materials. The first member **702** is solid and includes a wear-resistant, concave first contact surface **708**. The first contact surface **708** includes a protruding peripheral rim **710**, and a recessed central portion **712**, which may also be considered a "pocket" or a "relief".

The second member **704** is hollow and includes a dome **714** connected to a peripheral wall **716**. An interior cavity **718** is defined behind the dome **714**. The dome **714** defines a wear-resistant, convex second contact surface **720**, which is shaped and sized enough to permit bending under working loads, but not so as to allow material yield or fatigue cracking. The second contact surface **720** is thus conformable to the first contact surface **708** when the prosthetic joint **700** is placed under external load.

The first and second contact surfaces **708** and **720** bear directly against each other so as to transfer axial and lateral loads from one member to the other while allowing pivoting motion between the two members **702** and **704**.

Any of the contact surfaces described above may be provided with one or more grooves formed therein to facilitate flow of fluid or debris. For example, FIG. **23** illustrates a joint member **800** including a concave contact surface **802**. The contact surface **802** includes a circular groove **804**, and plurality of generally radially-extending grooves **806** which terminate at the center of the contact surface **802** and intersect the circular groove **804**.

FIGS. **31-33** illustrate an alternative prosthetic joint **1000** comprising first and second members **1002** and **1004**. The illustrated prosthetic joint **1000** is particularly adapted for a ball-and-socket joint application such as is found in a human hip joint (i.e. the acetabulofemoral joint) or shoulder joint (i.e. the glenohumeral joint), but it will be understood that the principles described herein may be applied to any type of prosthetic joint. Both of the members **1002** and **1004** may be bone-implantable, meaning they include osseointegration surfaces, labeled "S", which are surfaces designed to be infiltrated by bone growth to improve the connection between the implant and the bone. Osseointegration surfaces may be made from materials such as TRABECULAR METAL, textured metal, or sintered or extruded implant integration textures, as described above. As shown in FIG. **31**, a nominal central axis "A" passes through the centers of the first and second members **1002** and **1004** In the illustrated examples, the first and second joint members **1002** and **1004** are bodies of revolution about this axis, but the principles of the present invention also extend to non-axisymmetric shapes.

The first member **1002** is constructed from a rigid material as described above. The first member **1002** is concave and may generally be thought of as a "cup", although it need not have any particular degree of curvature. Its interior defines a nominal cup surface **1006** shown by the dashed line in FIG. **33**. The interior includes an annular first flange **1008** which is located relatively near an apex **1010** of the first member **1002** and which extends in a generally radial direction relative to the axis A. The first flange **1008** is defined in part by an undercut groove **1012** formed in the first member **1002**. A ramped surface **1014** forms a transition from the groove **1012** to the nominal cup surface **1006**. The first flange **1008** includes a protruding first contact rim **1016**. As used herein, the term "protruding" as applied to the first contact rim **1016** means that the first contact rim **1016** lies inside of the nominal cup surface **1006** when the joint **1000** is assembled. The first contact rim **1016** may have a curved or toroidal cross-sectional shape.

The interior also includes an annular second flange **1018** which is located at or near an outer peripheral edge **1020** of the first member **1002** and which extends in a generally axial direction relative to the axis A. The second flange **1018** is defined in part by an undercut groove **1022** formed in the first member **1002**. The second flange **1018** includes a protruding second contact rim **1024**. As used herein, the term "protruding" as applied to the second contact rim **1024** means that the second contact rim **1024** lies inside of the nominal cup surface **1006** when the joint **1000** is assembled. The second contact rim **1024** may have a curved or toroidal cross-sectional shape. Depending on the particular application, joint **1000** may include more than two flanges defining more than two contact rims.

In the illustrated example, the first member **1002** includes a face layer **1026** of a known coating such as titanium nitride, chrome plating, carbon thin films, and/or diamond-like carbon coatings, and/or a another substantially thicker wear-resistant material such as ultra-high molecular weight (UHMW) polyethylene. This face layer **1026** is used to impart wear resistance, as described above. The face layer **1026** may be extraordinarily thin. In this particular example, its as-applied thickness is about 0.0041 mm (0.00016 in.), or 160 millionths of an inch thick. The face layer **1026** is applied at a substantially uniform thickness over the surface profile which is defined by machined or formed features of the substrate. Alternatively, and especially if a much thicker face layer were used, the face layer could be profiled so as to define both the nominal cup surface **1006** and the first and second contact rims **1016** and **1024**.

The second member **1004** is also made from a rigid material and has a wear-resistant, convex contact surface **1028**. In the specific example illustrated, the second member **1004** includes a face layer **1030** of a known coating such as titanium nitride, chrome plating, carbon thin films, and/or diamond-like carbon coatings, and/or a another substantially thicker wear-resistant material such as ultra-high molecular weight (UHMW) polyethylene. This face layer **1030** is used to impart wear resistance, and may be quite thin, as described above. The first and second contact rims **1016** and **1024** bear directly against the contact surface **1028** so as to transfer axial and lateral loads from one member to the other while allowing pivoting motion between the two members **1002** and **1004**.

The annular configuration of contact rims **1016** and **1024** results in a joint configuration which permits only pivoting and rotational motion, and is statically and dynamically determinate for the life of the joint **1000**. In particular, the presence of the relatively widely-spaced contact rims **1016** and **1024**, and the peripheral positioning of the second contact rim **1024** is highly effective in resisting any translation of the first and second members **1002** and **1004** lateral to the axis A.

Nominally the first and second contact rims **1016** and **1024** define two separate "ring" or "band" contact interfaces with the contact surface **1028** of the second member **1004**. In practice it is impossible to achieve surface profiles completely free of minor imperfections and variations. If the first and second members **1002** and **1004** were both completely rigid, this would cause high Hertzian contact stresses (i.e. non-uniform contact) and rapid wear. Accordingly, an important feature of the illustrated joint **1000** is that the flanges **1008** and **1018** (and thus the contact rims **1016** and **1024**) of the first member **1002** are conformable to the contact surface **1028** when the joint **1000** is placed under load. The flanges **1008** and **1018** can conform to the imperfect contact surface **1028** and deflect in an irregular shape. In other words, in addition to any uniform deflection which may be present, the deflected shape of the flanges **1008** and **1018** can include one or more specific locations or portions that are deflected towards or away from the nominal free shape to a greater or lesser degree than the remainder of the flanges **1008** and **1018**. To achieve this controlled deflection, the flanges **1008** and **1018** are thin enough to permit bending under working loads, but not so thin as to allow material yield or fatigue cracking, or to exceed the endurance limit of the material. The deflection is opposed by the elasticity of the flanges **1008** and **1018** in bending, as well as the hoop stresses in the flanges **1008** and **1018**.

The contact rims **1016** and **1024** are designed in conjunction with the contact surface **1028** to create a wear characteristic that is constantly diminishing (similar to an asymptotic characteristic). With reference to FIG. **32**, the as-manufactured or initial curvatures (e.g. radii) of the first and second contact rims **1016** and **1024**, denoted "R" are different from the curvature (e.g. radius) of the contact surface **1028**, denoted "r". It is noted that the direction of curvature (i.e. the convexity or second derivative shape) of the first and second contact rims **1016** and **1024** may be the same as, or opposite to, that of the contact surface **1028** upon initial manufacture. In this example they are opposite. When assembled and placed under load, the annular interface between each of the contact rims **1016** and **1024** and the contact surface **1028** will have a characteristic width denoted "W", (effectively creating a contact band). The initial dimensions R and r are selected such that, even using highly wear-resistant surfaces or coatings, some wear takes place during an initial wear-in period of movement cycles. As a result, the contact band width W increases during the initial wear-in period. This increases contact area and therefore decreases contact stress for a given load. After the initial wear-in period (which preferably occurs before the joint is implanted), the contact band reaches a post wear-in width at which the contact stress is below a selected limit, below which the rate of wear in the contacting surfaces approaches a very low number or zero, consistent with a long life of the joint **1000**. FIG. **36** illustrates this wear characteristic, with the limit "L" depicted as a horizontal line.

FIGS. **34** and **35** are schematic views showing the initial wear-in of the surface of the contact rim **1016** at a microscopic (or nearly microscopic) level. It will be understood that these figures are greatly exaggerated for the purposes of illustration. On initial manufacture, as shown in FIG. **34**, the curvatures R and r of the contact rim **1016** and the contact surface **1028** have opposite directions. When assembled, the contact band width W is some nominal value, for example about 0.03 mm (0.001 in.), and the total thickness "T" of the face layer

1026 is at its as-applied value of about 0.0041 mm (0.00016 in.) for example. The action of the wear-in period described causes the face layer 1026 to wear to a shape complementary to the contact surface 1028. After this wear-in period the curvature of the portion of the contact rim 1016 within the contact band, denoted "R", and the curvature r of the contact surface 1028 are in the same direction, and the values of the two curvatures are substantially the same. For example, the thickness T at the location of the contact band may decrease by about 0.0004 mm (0.000014 in.), with a corresponding increase in the width of the contact band W to about 0.2 mm (0.008 in.). Analysis shows that this increase in contact band width and surface area can reduce mean contact pressure by over 80%.

The configuration of the flanges 1008 and 1018 are important in developing the constantly diminishing wear characteristics described above. In particular, the flanges 1008 and 1018 are sized and shaped so that deflections of the contact rims 1016 and 1024 under varying load are always essentially normal to their respective tangent points on the opposing contact surface 1028, as the joint 1000 is loaded and unloaded. This ensures that the position of each of the contact bands remains constant and that the contact bands remain substantially uniform around the entire periphery of the joint 1000.

An inverted configuration of the joint described above may be used. For example, FIGS. 37 and 38 illustrate a prosthetic joint 1100 having first and second members 1102 and 1104 which are substantially similar in general construction to the members of the joint 1000 described above in terms of materials, coatings, and so for forth. However, in this joint 1100, the concave member 1102 has a contact surface without protruding rings. The convex member 1104 has first and second flanges 1108 and 1118 which define first and second contact rims 1116 and 1124 which function in the same manner that the flanges and contact rims described above.

FIG. 39 illustrates an alternative prosthetic joint 1200 comprising first and second members 1202 and 1204. The illustrated prosthetic joint 1200 is generally similar in construction and function to the prosthetic joint 1000 described above, and one or both of the members 1202 and 1204 may be bone-implantable as described above.

A For purposes of explanation and illustration the first member 1202 will be described relative to a "balanced centroidal axis", labeled "N1" in FIG. 39, passing through it. As used herein, the term "balanced centroidal axis" refers to a virtual line, parallel to local gravity (i.e. a local vertical), which passes through the geometric centroid of the first member 1202, labeled "C", when the first member is in a balanced position (i.e. when there is no rotation of the first member due to unbalanced mass). It is noted that, where the first member 1202 is presumed to have a uniform density, the centroid C will be co-located with its center of mass. If the first member 1202 were suspended in a balanced condition by a point "P" vertically above the centroid C the balanced centroidal axis N1 would coincide with a local vertical axis passing through the centroid C. In the case where the first member 1202 is a body of revolution, the balanced centroidal axis N1 would coincide or nearly coincide with the generating axis of the first member 1202.

The first member 1202 is constructed from a rigid material and may generally be thought of as a "cup", as described above. Its interior defines a nominal cup surface 1206. The interior includes a cantilevered first flange 1208, defined in part by an undercut groove 1212 formed in the first member 1202. Without regard to the exact direction that the flange 1208 extends, it may be considered to be cantilevered relative to the remainder of the first member 1202. In other words, when viewed in cross-section, it is a projecting structure, that is supported at one end and carries a load at the other end or along its length. A ramped surface 1214 forms a transition from the groove 1212 to the nominal cup surface 1206. The first flange 1208 includes a protruding first contact rim 1216. The first contact rim 1216 may have a straight, curved, or toroidal cross-sectional shape.

The first flange 1208 has an angular offset relative to the balanced centroidal axis N1. In other words, the first flange 1208 is asymmetric to the balanced centroidal axis N1. This is also referred to as a "non-axisymmetric" condition. In the particular example and view shown in FIG. 39, the first flange 1208 is offset to the right side of the figure. The angular offset or asymmetric position allows the functional characteristics of the first flange 1208 to be tailored to specific operating conditions encountered by the prosthetic joint 1200. For example, the angular offset may be selected so that the first flange is aligned with an expected primary load vector.

The interior also includes a cantilevered second flange 1218 which is defined in part by an undercut groove 1222 formed in the first member 1202. The second flange 1218 includes a protruding second contact rim 1224. The second contact rim 1224 may have a straight, curved, or toroidal cross-sectional shape.

The second member 1204 is also made from a rigid material and has a wear-resistant, convex contact surface 1228. The first and second contact rims 1216 and 1224 bear directly against the contact surface 1228 so as to transfer axial and lateral loads from one member to the other while allowing pivoting motion between the two members 1202 and 1204. The annular configuration of contact rims 1216 and 1224 results in a joint configuration which permits only pivoting and rotational motion, and is statically and dynamically determinate for the life of the joint 1200.

Nominally the first and second contact rims 1216 and 1224 define two separate "ring" or "band" contact interfaces with the contact surface 1228 of the second member 1204. The flanges 1208 and 1218 (and thus the contact rims 1216 and 1224) of the first member 1202 are conformable to the contact surface 1228 when the joint 1200 is placed under load. The flanges 1208 and 1218 can conform to the imperfect contact surface 1228 and deflect in an irregular shape, in the manner described above for the joint 1200.

The facing surfaces of either or both of the first and second members 1202 and 1204 may include a face layer of a known coating such as titanium nitride, chrome plating, carbon thin films, and/or diamond-like carbon coatings, and/or a another substantially thicker wear-resistant material such as ultra-high molecular weight (UHMW) polyethylene. This face layer is used to impart wear resistance, as described above.

Depending on the specific application, the second flange 1218 may have an angular offset like the first flange 1208. For example, FIG. 40 illustrates a prosthetic joint 1200' substantially similar in construction to the prosthetic joint 1200, with first and second members 1202' and 1204'. The first member 1202' has a balanced centroidal axis "N1", and first and second flanges 1208' and 1218'. The first flange 1208' is angularly offset from the balanced centroidal axis N1' (i.e. it is asymmetric relative to the balanced centroidal axis N1') and the second flange 1218 is also angularly offset from the nominal axis N1' (i.e. it is asymmetric relative to the balanced centroidal axis N1').

The flange of the joint members described above need not be circular, elliptical, or another symmetrical shape in plan view, and need not lie in a single plane. For example, FIGS. 41-43 illustrate a joint member 1302. Its interior defines a nominal cup surface **1306**. The interior includes a cantilevered first flange **1308**, defined in part by an undercut groove **1312** formed in the first member **1302**. The first flange **1308** includes a protruding first contact rim **1316**. The first contact rim **1316** may have a straight, curved, or toroidal cross-sectional shape. The interior also includes a cantilevered second flange **1318** which is defined in part by an undercut groove **1322** formed in the first member **1302**. The second flange **1318** includes a protruding second contact rim **1324**. The second contact rim **1324** may have a straight, curved, or toroidal cross-sectional shape.

The first flange **1308** (and therefore the first contact rim **1316**) have a "saddle" shape. In this particular example it has a racetrack shape in plan view, and the portions at the ends of the major axis of the racetrack shape are elevated (in the z-direction) relative to the remainder of the shape. The first contact rim **1316** is shaped so as to define a contact band in which some or all points on its surface lie on a sphere (or otherwise match the shape of the mating convex joint member described above). The second flange **1318** could have a similar saddle shape as well.

The prosthetic joints described herein may include one or more flanges with an open perimeter. For example, FIGS. **44** and **45** illustrate another alternative prosthetic joint **1400** comprising first and second members **1402** and **1404**. The illustrated prosthetic joint **1400** is generally similar in construction and function to the prosthetic joint **1000** described above, and one or both of the members **1402** and **1404** may bone-implantable as described above.

A balanced centroidal axis "N2", may be considered to pass through the first member **1402**. This axis N2 is defined in the same manner as the balanced centroidal axis "N1" described above. The first member **1402** is constructed from a rigid material and may generally be thought of as a "cup", as described above. Its interior defines a nominal cup surface **1406**. The interior includes a cantilevered first flange **1408**, defined in part by an undercut groove **1412** formed in the first member **1402**. A ramped surface **1414** forms a transition from the groove **1412** to the nominal cup surface **1406**. The first flange **1408** includes a protruding first contact rim **1416**. The first contact rim **1416** may have a straight, curved, or toroidal cross-sectional shape.

The first flange **1408** has an angular offset relative to the balanced centroidal axis N**2**, in other words it is asymmetric relative to the balanced centroidal axis N**2**. The interior also includes a cantilevered second flange **1418** which is defined in part by an undercut groove **1422** formed in the first member **1402**. The second flange **1418** includes a protruding second contact rim **1424**. The second contact rim **1424** may have a straight, curved, or toroidal cross-sectional shape.

In the example shown in FIGS. **44** and **45**, the second flange **1418** is also angularly offset from the balanced centroidal axis N2, i.e. it is asymmetric relative to the balanced centroidal axis.

The interior also includes a cantilevered third flange **1429** which is defined in part by an undercut groove **1430** formed in the first member **1402**. The third flange **1418** includes a protruding third contact rim **1432**. The third contact rim **1432** may have a straight, curved, or toroidal cross-sectional shape. As best seen in FIG. **45**, the third flange **1429** has an open perimeter, circumscribing less than 360 degrees. The distal ends of the third flange **1429** may be feathered away from the nominal cup surface, for example either by tapering the third flange's thickness or by tilting the distal ends outward relative to the remainder of the flange, so as not to contact the contact surface **1428** of the second member **1404**.

The third flange **1429** could be symmetric or asymmetric relative to the balanced centroidal axis N**2**.

The second member **1402** is also made from a rigid material and has a wear-resistant, convex contact surface **1428**. The first, second, and third contact rims **1416**, **1424**, and **1432**, bear directly against the contact surface **1428** so as to transfer axial and lateral loads from one member to the other while allowing pivoting motion between the two members **1402** and **1404**.

Nominally the first, second, and third contact rims **1416**, **1424**, and **1432** define three separate "ring" or "band" contact interfaces with the contact surface **1428** of the second member **1404**. The flanges **1408**, **1418**, and **1429** (and thus the contact rims **1216**, **1224**, and **1432**) of the first member **1402** are conformable to the contact surface **1428** when the joint **1400** is placed under load. The flanges **1408**, **1418**, and **1429** can conform to the imperfect contact surface **1428** and deflect in an irregular shape, in the manner described above for the joint **1000**.

The facing surfaces of either or both of the first and second members **1402** and **1404** may include a face layer of a known coating such as titanium nitride, chrome plating, carbon thin films, and/or diamond-like carbon coatings, and/or a another substantially thicker wear-resistant material such as ultra-high molecular weight (UHMW) polyethylene. This face layer is used to impart wear resistance, as described above.

Any of the flanges may have an open perimeter. For example, FIGS. **46** and **47** illustrate a prosthetic joint **1400'** similar in construction to the prosthetic joint **1400**, including first and second members **1402'** and **1404'**. The first member **1402'** includes cantilevered first, second, and third flanges **1408'**, **1418'**, and **1429'**. In this example the first and third flanges **1408'** and **1429'** have a closed perimeter, and the second flange **1418'** has an open perimeter, circumscribing less than 360 degrees. Any or all of the flanges **1408'**, **1418'**, and **1429'** may be angularly offset from (i.e. asymmetric relative to) a balanced centroidal axis "N**3**" of the first member **1402'**, as described above. The construction and function of the joint **1400'** is otherwise identical to the joint **1400**. As described above for the flange **1429**, the distal ends of any flange having an open perimeter may be feathered away from the nominal cup surface, for example either by tapering the flange's thickness or by tilting the distal ends outward relative to the remainder of the flange, so as not to contact the contact surface of opposing member

FIGS. **48** and **49** illustrate a prosthetic joint member **1502**, which may be used with any of the convex joint members described above.

The member **1502** is constructed from a rigid material and generally has a concave "cup" shape as described above. It may also be bone-implantable as described above. Its interior defines a nominal cup surface **1506**. The interior includes a cantilevered flange **1508**, defined in part by an undercut groove **1512** formed in the first member **1502**. A ramped surface **1514** forms a transition from the groove **1512** to the nominal cup surface **1506**. The flange **1508** includes a protruding first contact rim **1516**. The first contact rim **1516** may have a straight, curved, or toroidal cross-sectional shape. The flange **1508** may include an angular offset relative to a balanced centroidal of the joint member **1502**, as described above.

A peripheral groove **1520** is formed in the nominal cup surface **1506**. In the example shown in FIGS. **48** and **49**, it has a "T"-shaped cross-section. A contact ring **1522** is received in the groove **1520**. A part of the contact ring **1522** protrudes from the nominal cup surface **1506** and defines a second contact rim **1524**. In the illustrated example, the contact ring

1522 has "hat section" cross-sectional shape, with distal flanges that are received in the T-shaped groove 1520.

The contact ring 1522 is made of a rigid material and has a wear-resistant surface, as those terms are described above. It is sized and shaped to achieve controlled elastic deflection, and to be conformable in the manner of the flanges described above. Its construction is thin enough to permit bending under working loads, but not so thin as to allow material yield or fatigue cracking. Deflection of the contact ring 1522 is opposed by the elasticity of the contact ring 1522 in bending, as well as the hoop stresses therein. To achieve long life, the contact ring 1522 is sized so that stresses therein will be less than the endurance limit of the material.

Various cross-sectional shapes may be used for the contact ring. For example, FIG. 50 illustrates a contact ring 1522' with a "Z" shape and a doubled-over retention flange 1523. FIG. 51 illustrates a contact ring 1522" with a circular cross-section. The grooves 1520' and 1520" are modified to accommodate their respective contact rings 1522' and 1522".

Nominally the first and second contact rims 1516 and 1524 define two separate "ring" or "band" contact interfaces with the contact surface of the opposed convex member (not shown). The contact rims 1516 and 1524 are conformable to an opposed contact surface when the joint is placed under load.

Any of the joint members described above may include holes or apertures formed therein to reduce their weight, or to facilitate manufacture or installation. For example, FIG. 52 illustrates a cup joint member 1602 with first and second flanges 1608 and 1618, and an aperture 1610 formed near the apex of the cup shape.

While the joint members have been illustrated above with monolithic construction, any of the joint members may be made from one or more components built up to form the whole. For example, FIG. 53 illustrates a joint member 1702 which is a cup having a first flange 1708 and a second flange 1718 as described above. The joint member 1702 is made up from an annular first section 1710 and a cap-like second section 1711 which fit together to form the completed cup shape. The two sections 1710 and 1711 are fixed to each other, for example by a mechanical (e.g. interference) fit, an adhesive, welding or other thermal bonding method, or fasteners.

FIG. 54 illustrates a prosthetic joint member 1802, which may be used with any of the convex joint members described above.

The member 1802 is constructed from a rigid material and generally has a concave "cup" shape as described above. It may also be bone-implantable as described above. It is made up from a shell 1804 with an interior surface 1806, and a liner 1808 which fits conformally against the interior surface 1806. The liner 1808 may be fixed or moveable relative to the shell 1804. An interior of the liner 1808 defines a nominal cup surface 1810. The liner 1808 includes a first peripheral ring 1812, defined as a generally "U"-shape formed in the liner 1808. The first peripheral ring 1812 includes a protruding first contact rim 1816. The first contact rim 1816 may have a straight, curved, or toroidal cross-sectional shape. The first peripheral ring 1812 may include an angular offset or asymmetric positioning relative to a balanced centroidal axis "N4" of the joint member 1802, as that concept is described above.

The liner 1808 also includes a second peripheral ring 1818, defined as a generally "U"-shape formed in the liner 1808. The second peripheral ring 1818 includes a protruding second contact rim 1820. The second contact rim 1820 may have a straight, curved, or toroidal cross-sectional shape. The second peripheral ring 1818 may include an angular offset relative to a balanced centroidal axis "N4" of the joint member 1802, as that concept is described above.

The liner 1808 is made of a rigid material and has a wear-resistant surface, as those terms are described above. The first and second peripheral rings 1812 and 1818 are sized and shaped to achieve controlled elastic deflection, and to be conformable in the manner of the flanges described above. Their construction is thin enough to permit bending under working loads, but not so thin as to allow material yield or fatigue cracking. Deflection of the contact rings 1812 and 1818 are opposed by the elasticity of the rings in bending, as well as the hoop stresses therein. To achieve long life, the contact rings 1812 and 1818 are sized so that stresses therein will be less than the endurance limit of the material.

Nominally the first and second contact rims 1816 and 1820 define two separate "ring" or "band" contact interfaces with the contact surface of the opposed convex member (not shown). The contact rims 1816 and 1820 are conformable to the opposed contact surface when the joint is placed under load.

FIGS. 55-58 illustrate an alternative prosthetic joint member 1902. The illustrated prosthetic joint member 1902 is generally similar in construction and function to the prosthetic joint member 1202 described above, and is intended to be used with a complementary joint member having a convex or ball-like structure, such as the joint member 1204, in order to constitute a complete prosthetic joint.

For purposes of explanation and illustration the joint member 1902 will be described relative to a "balanced centroidal axis", labeled "N5" in FIG. 55, passing through it. The meaning of the term "balanced centroidal axis" is described above.

The joint member 1902 includes a cup 1904 and an insert 1906. The cup 1904 has interior and exterior surfaces 1908 and 1910, respectively. The exterior surface 1910 may be configured to be bone-implantable as described above. A peripheral rim 1912 extends around the open edge of the cup 1904. The peripheral rim 1912 includes a first indexing feature 1914 formed therein. In the particular example illustrated, the first indexing feature is a plurality of grooves or slots.

The insert 1906 is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface 1916. The interior is configured similar to that of the joint member 1202 described above and includes a cantilevered first flange 1918, defined in part by an undercut groove 1920 formed in the nominal surface 1916. The first flange 1918 has an angular offset relative to the balanced centroidal axis N5, and the first flange 1918 includes a protruding first contact rim 1922. The first contact rim 1922 may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange 1924 which is defined in part by an undercut groove 1926 formed in the nominal surface 1916. The second flange 1924 includes a protruding second contact rim 1928. The second contact rim 1928 may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange 1924 may have an angular offset like the first flange 1918. The flanges 1918 and 1924 (and thus the contact rims 1922 and 1928) of the joint member 1902 are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges 1918 and 1924 can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint 1000 described above. Contact between the contact rims and the contact surface of an opposed convex joint member permits transfer of axial and lateral loads from one member to the other while allowing pivoting motion between the two members.

A peripheral rim **1930** extends around the open edge of the insert **1906**. The peripheral rim **1930** includes a second indexing feature **1932** formed therein. In the particular example illustrated, the second indexing feature **1932** is a plurality of tabs or ribs.

When the insert **1906** is assembled to the cup **1904**, the first and second indexing features **1914** and **1932** engage each other and prevent relative rotation of the cup **1904** and the insert **1906** (i.e. retaining the insert **1906** in a fixed angular orientation relative to the cup **1904**). The construction of the indexing features may be modified or inverted as needed to suit a particular application. For example, the peripheral rim **1930** of the insert **1906** may include slots or grooves while the peripheral rim **1912** of the cup **1904** could have tabs or ribs. The indexing features **1914** or **1932** may have a tapered or wedge shape to ensure that any clearance present between the two is taken up upon assembly of the cup **1904** to the insert **1906**.

The joint member **1902** may be implanted by first placing the cup **1904** into a prepared bone surface (not shown), then selecting a specific orientation for the insert **1906**. The insert **1906** is then placed into the cup **1904** in the selected orientation. The first and second indexing features **1914** and **1932** ensure that this orientation is maintained. Typically the cup **1904** would be placed using bone cement or a fastening process which must be completed in one step, or it would be difficult and/or undesirable to remove and replace the cup **1904**. Because the cup **1904** and the insert **1906** are separate from each other, there is no need to maintain any particular rotational alignment of the cup **1904** about the axis **N5** as it is placed, yet the insert **1906** can be clocked relative to the cup **1904** to place the flanges **1918** and **1924** in a precise orientation when finally assembled.

FIG. **59** illustrates an alternative prosthetic joint member **2002**. It is generally similar in construction and function to the prosthetic joint member **1902** described above, and includes a cup **2004** and an insert **2006**. The cup **2004** has interior and exterior surfaces **2008** and **2010**, respectively, and the exterior surface **2010** may be configured to be bone-implantable as described above. A first indexing feature **2014** is formed in the interior of the cup **2004** adjacent the open edge of the cup **2004**. In the particular example illustrated, the first indexing feature **2014** is a plurality of axially-aligned grooves or slots.

The insert **2006** is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface **2016**. The interior is configured similar to that of the joint member **1202** described above and includes a cantilevered first flange **2018**, defined in part by an undercut groove (not visible) formed in the nominal surface **2016**. The first flange **2018** has an angular offset relative to a balanced centroidal axis N**6** of the insert **2006**, and the first flange **2018** includes a protruding first contact rim **2022**. The first contact rim **2022** may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange **2024** which is defined in part by an undercut groove **2026** formed in the nominal surface **2016**. The second flange **2024** includes a protruding second contact rim **2028**. The second contact rim **2028** may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange **2024** may have an angular offset like the first flange **2018**. The flanges **2018** and **2024** (and thus the contact rims **2022** and **2028**) of the joint member **2002** are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges **2018** and **2024** can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint **1000** described above.

A second indexing feature **2032** is formed on the exterior of the insert **2006**, adjacent its open edge. In the particular example illustrated, the second indexing feature **2032** is a plurality of axially-aligned ribs protruding radially outward. The ribs have a cross-sectional shape which is complementary to the grooves of the first indexing feature **2014**.

The joint member **2002** may be implanted using the process described above for the joint member **1902**. When the insert **2006** is assembled to the cup **2004**, the first and second indexing features **2014** and **2032** engage each other and prevent relative rotation of the cup **2004** and the insert **2006**. The construction of the indexing features may be modified or inverted as needed to suit a particular application. For example, the insert **2006** may include slots or grooves while the cup **2004** could have tabs or ribs. The indexing features **2014** or **2032** may have a tapered or wedge shape to ensure that any clearance present between the two is taken up upon assembly of the cup **2004** to the insert **2006**.

FIGS. **60-62** illustrate an alternative prosthetic joint member **3002**. The illustrated prosthetic joint member **3002** is generally similar in construction and function to the prosthetic joint member **1202** described above, and is intended to be used with a complementary joint member having a convex or ball-like structure, such as the joint member **1204**, in order to constitute a complete prosthetic joint.

For purposes of explanation and illustration the joint member **3002** will be described relative to a "balanced centroidal axis", labeled "N7" in FIG. **60**, passing through it. The meaning of the term "balanced centroidal axis" is described above.

The joint member **3002** includes a cup **3004** and an insert **3006**. The cup **3004** has interior and exterior surfaces **3008** and **3010**, respectively. The exterior surface **3010** may be configured to be bone-implantable as described above. The interior surface **3008** has an annular retention groove **3012** formed therein. The retention groove includes a side wall **3013** and an end wall **3015**. The end wall **3015** may be angled, as shown in FIG. **61**, so that its inboard end is closer to the open end of the cup **3004** than its outboard end.

The insert **3006** is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface **3016**. The interior is configured similar to that of the joint member **1202** described above and includes a cantilevered first flange **3018**, defined in part by an undercut groove **3020** formed in the nominal surface **3016**. The first flange **3018** has an angular offset relative to the balanced centroidal axis N7, and the first flange **3018** includes a protruding first contact rim **3022**. The first contact rim **3022** may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange **3024** which is defined in part by an undercut groove **3026** formed in the nominal surface **3016**. The second flange **3024** includes a protruding second contact rim **3028**. The second contact rim **3028** may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange **3024** may have an angular offset like the first flange **3018**. The flanges **3018** and **3024** (and thus the contact rims **3022** and **3028**) of the joint member **3002** are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges **3018** and **3024** can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint **1000** described above.

As best seen in FIG. **62**, a plurality of retention tabs **3030** extend outward from an outer surface **3032** of the insert **3006**. In the illustrated example the retention tabs **3030** are integrally formed with the insert **3006**, but they could be formed separately and then attached to the insert **3006**. The retention tabs **3030** are cantilevered spring members and are sized and shaped to fit into the retention groove **3012** of the cup **3004**. As shown the retention tabs **3030** are arrayed evenly around the periphery of the insert **3006**. The specific configuration of the retention tabs **3030** may be altered to suit a particular application, for example the angular width, length, thickness, and number of tabs may be altered as needed.

Referring to FIGS. **60** and **61**, when the insert **3006** is assembled to the cup **3004**, the retention tabs **3030** will be deflected inward. When the insert is fully seated the retention tabs **3030** will spring outward into the retention groove **3012**, holding the insert **3006** securely engaged with the cup **3004**. The retention tabs **3030** may be configured to have a "self-locking" function, such that their engagement with the retention groove **3012** is assured even if the insert **3006** is displaced further into the cup **3004**. For example, as shown in FIG. **61**, each retention tab **3030** includes an end face **3031** which is roughly parallel to the angled end wall **3015** of the retention groove **3012**. Initial contact with the end wall **3015** limits the outward motion of the retention tabs **3030** before they contact the side wall **3013**. It can be seen that if the insert **3006** is advanced further into the cup **3006** the retention tabs **3030** will spring outward an additional amount allowing the end face **3031** to advance further along the end wall **3015**, but always maintaining contact.

FIGS. **63** and **64** illustrate an alternative prosthetic joint member **4002**. The illustrated prosthetic joint member **4002** is generally similar in construction and function to the prosthetic joint member **3002** described above, and is intended to be used with a complementary joint member having a convex or ball-like structure, such as the joint member **1204**, in order to constitute a complete prosthetic joint.

For purposes of explanation and illustration the joint member **4002** will be described relative to a "balanced centroidal axis", labeled "**N8**" in FIG. **63**, passing through it. The meaning of the term "balanced centroidal axis" is described above.

The joint member **4002** includes a cup **4004** and an insert **4006**. The cup **4004** has interior and exterior surfaces **4008** and **4010**, respectively. The exterior surface **4010** may be configured to be bone-implantable as described above. The interior surface **4008** has a first detent element **4012** formed therein, in this particular example a concave groove. The first detent element **4012** could be a continuous annular groove, or it could comprise an annular array of individual recesses.

The insert **4006** is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface **4016**. The interior is configured similar to that of the joint member **3002** described above and includes a cantilevered first flange **4018**, defined in part by an undercut groove **4020** formed in the nominal surface **4016**. The first flange **4018** has an angular offset relative to the balanced centroidal axis N8, and the first flange **4018** includes a protruding first contact rim **4022**. The first contact rim **4022** may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange **4024** which is defined in part by an undercut groove **4026** formed in the nominal surface **4016**. The second flange **4024** includes a protruding second contact rim **4028**. The second contact rim **4028** may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange **4024** may have an angular offset like the first flange **4018**. The flanges **4018** and **4024** (and thus the contact rims **4022** and **4028**) of the joint member **4002** are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges **4018** and **4024** can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint **1000** described above.

A second detent feature **4030**, in this particular example a convex rib, is formed on an outer surface **4032** of the insert **3006**. The second detent feature **4030** could be a continuous protruding annular rib, or it could comprise an annular array of individual, dome-like protrusions. The second detent element **4030** is sized and shaped to fit into the first detent elements **4012** of the cup **4004**. Cooperatively, the detent elements **4012** and **4030** function as a "detent" in the sense that, when the detent elements **4012** and **4030** are engaged with each other, they prevent relative movement of the cup **4004** and the insert **4006**. The specific configuration of the detent elements **4012** and **4030** may be altered to suit a particular application, for example the shape, size, and number of the detent elements may be altered as needed. Furthermore the concave/convex relationship between the detent elements **4012** and **4030** may be reversed.

When the insert **4006** is assembled to the cup **4004**, the second detent elements **4030** will engage the first detent element **4012**, holding the insert **4006** securely engaged with the cup **4004**. In cases where the first and second detent elements **4012** and **4030** each comprise a plurality of discrete members, the cooperating detent elements would also serve to positively index the relative angular orientation of the cup **4004** and the insert **4006**, in the manner described above.

FIG. **65** illustrates an alternative prosthetic joint member **5002**. The illustrated prosthetic joint member **5002** is generally similar in construction and function to the prosthetic joint member **1202** described above, and is intended to be used with a complementary joint member having a convex or ball-like structure, such as the joint member **1204**, in order to constitute a complete prosthetic joint.

For purposes of explanation and illustration the joint member **5002** will be described relative to a "balanced centroidal axis", labeled "**N9**" in FIG. **65**, passing through it. The meaning of the term "balanced centroidal axis" is described above.

The joint member **5002** includes a cup **5004** and an insert **5006**. The cup **5004** has interior and exterior surfaces **5008** and **5010**, respectively. The exterior surface **5010** may be configured to be bone-implantable as described above.

The insert **5006** is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface **5016**. The interior is configured similar to that of the joint member **1202** described above and includes a cantilevered first flange **5018**, defined in part by an undercut groove **5020** formed in the nominal surface **5016**. The first flange **5018** has an angular offset relative to the balanced centroidal axis N9, and the first flange **5018** includes a protruding first contact rim **5022**. The first contact rim **5022** may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange **5024** which is defined in part by an undercut groove **5026** formed in the nominal surface **5016**. The second flange **5024** includes a protruding second contact rim **5028**. The second contact rim **5028** may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange **5024** may have an angular offset like the first flange **5018**. The flanges **5018** and **5024** (and thus the contact rims **5022** and **5028**) of the joint member **5002** are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges **5018** and **5024** can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint **1000** described above.

A compliant spacer **5030** is disposed between the cup **5004** and the insert **5006**. The spacer **5030** is constructed from a material that is sufficiently "soft" to deform compliantly when the insert **5006** is installed in the cup **5004**. Nonlimiting examples of suitable materials for the spacer **5030** include polymers and elastomeric materials. The spacer **5030** is fixed relative to the insert **5006**. One function of the spacer **5030** is to compliantly support the insert **5006** inside the cup **5004**. It is possible that the cup **5004** can be implanted so that its interior surface **5008** is distorted from a nominal shape. Rigid installation of the insert **5006** directly against the cup **5004** could in turn cause excessive distortion of the insert **5006**. In such situations the compliant nature of the spacer **5006** allows the insert **5006** to remain in a nominal shape.

It is also possible for the spacer **5030** to provide overload protection to the joint member **5002**. Specifically, when the joint member **5002** is subjected to a load beyond the normal working range of the flanges **5018** and **5024**, the convex joint member will tend to "bottom out" against the insert **5006**, resulting in metal-to-metal contact with high local contact stresses. In such situations, the compliant nature of the spacer **5030** allows it to compress under loading and permit the insert **5006** to move towards the cup **5004**, relieving the high contact stresses. The spacer **5030** will return to its original shape and dimensions when the loading is removed.

FIGS. **66** and **67** illustrate another alternative prosthetic joint member **6002**. The illustrated prosthetic joint member **6002** is generally similar in construction and function to the prosthetic joint member **1202** described above, and is intended to be used with a complementary joint member having a convex or ball-like structure, such as the joint member **1204**, in order to constitute a complete prosthetic joint.

For purposes of explanation and illustration the joint member **6002** will be described relative to a "balanced centroidal axis", labeled "N**10**" in FIG. **66**, passing through it. The meaning of the term "balanced centroidal axis" is described above.

The joint member **6002** includes a cup **6004** and an insert **6006**. The cup **6004** has interior and exterior surfaces **6008** and **6010**, respectively. The exterior surface **6010** may be configured to be bone-implantable as described above. First and second annular spacer grooves **6012** and **6014** are formed in the interior surface **6008**. Each spacer groove **6012** and **6014** has a generally "T"-shaped cross-sectional shape.

The insert **6006** is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface **6016**. The interior is configured similar to that of the joint member **1202** described above and includes a cantilevered first flange **6018**, defined in part by an undercut groove **6020** formed in the nominal surface **6016**. The first flange **6018** has an angular offset relative to the balanced centroidal axis N**10**, and the first flange **6018** includes a protruding first contact rim **6022**. The first contact rim **6022** may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange **6024** which is defined in part by an undercut groove **6026** formed in the nominal surface **6016**. The second flange **6024** includes a protruding second contact rim **6028**. The second contact rim **6028** may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange **6024** may have an angular offset like the first flange **6018**. The flanges **6018** and **6024** (and thus the contact rims **6022** and **6028**) of the joint member **6002** are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges **6018** and **6024** can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint **1000** described above.

A resilient first spacer ring **6030** is disposed between the cup **6004** and the insert **6006**. The first spacer ring **6030** has a cross-sectional shape generally referred to as a "hat" section with laterally-extending flanges **6032**. The flanges **6032** are received in the T-shaped first spacer groove **6012**. A second spacer ring **6034** of identical configuration to the first spacer ring **6030** is received in the second spacer groove **6014**. The first and second spacer rings **6030** and **6034** are configured so as to resiliently (or elastically) deflect under loading and permit the insert **6006** to move towards the cup **6004**, then return to its original shape and dimensions when the loading is removed. Nonlimiting examples of suitable materials for the spacer rings **6030** include metal alloys, polymers and elastomeric materials.

FIGS. **68** and **69** depict a joint member **7002** having a cup **7004** and insert **7006**. The insert **7006** is of identical construction to the insert **6006** described above. The cup **7004** is identical in construction to the cup **6004** described above except for the configuration of the first and second spacer grooves **7012** and **7014**, both of which have plain rectangular cross-sectional shapes.

A resilient first spacer ring **7030** is disposed between the cup **7004** and the insert **7006**. The first spacer ring **7030** has a closed-loop cross-sectional shape (e.g. circular, oval, or elliptical). A second spacer ring **7034** of identical configuration to the first spacer ring **7030** is received in the second spacer groove **7014**. The first and second spacer rings **7030** and **7034** are configured so as to resiliently (or elastically) deflect under loading and permit the insert **7006** to move towards the cup **7004**, then return to its original shape and dimensions when the loading is removed. Nonlimiting examples of suitable materials for the spacer rings **7030** and **7034** include metal alloys, polymers and elastomeric materials.

FIG. **70** illustrates another alternative prosthetic joint member **8002**. The illustrated prosthetic joint member **8002** is generally similar in construction and function to the prosthetic joint member **1202** described above, and is intended to be used with a complementary joint member having a convex or ball-like structure, such as the joint member **1204**, in order to constitute a complete prosthetic joint.

For purposes of explanation and illustration the joint member **8002** will be described relative to a "balanced centroidal axis", labeled "N**11**" in FIG. **70**, passing through it. The meaning of the term "balanced centroidal axis" is described above.

The joint member **8002** includes a cup **8004** and an insert **8006**. The cup **8004** has interior and exterior surfaces **8008** and **8010**, respectively. The exterior surface **8010** may be configured to be bone-implantable as described above. A peripheral rim **8012** extends around the open edge of the cup **8004**. The rim **8012** is shaped so as to define an annular, L-shaped interior corner or "step" **8014**.

The insert **8006** is constructed from a rigid material and has a generally hemispherical shape. Its interior defines a nominal surface **8016**. The interior is configured similar to that of the joint member **1202** described above and includes a cantilevered first flange **8018**, defined in part by an undercut groove **8020** formed in the nominal surface **8016**. The first flange **8018** has an angular offset relative to the balanced centroidal axis N**11**, and the first flange **8018** includes a protruding first contact rim **8022**. The first contact rim **8022** may have a straight, curved, or toroidal cross-sectional shape.

The interior also includes a cantilevered second flange **8024** which is defined in part by an undercut groove **8026** formed in the nominal surface **8016**. The second flange **8024** includes a protruding second contact rim **8028**. The second contact rim **8028** may have a straight, curved, or toroidal cross-sectional shape. Depending on the specific application, the second flange **8024** may have an angular offset like the first flange **8018**. The flanges **8018** and **8024** (and thus the contact rims **8022** and **8028**) of the joint member **8002** are conformable to the contact surface of an opposed convex joint member when the joint is placed under load. The flanges **8018** and **8024** can conform to the imperfect contact surface and deflect in an irregular shape, in the manner described above for the joint **1000** described above.

An annular lip **8030** extends radially outward from the open edge of the insert **8006**. The lip **8030** is received in the step **8014** of the cup **8004**. The dimensions of the cup **8004** and the insert **8006**, and the position of the step **8014** and the lip **8030** are selected such that, when the lip **8030** and the step **8014** are in contact, a definite clearance **8032** is present between the cup **8004** and the insert **8006**.

This clearance allows the insert **8006** to resiliently deflect under loading and move towards the cup **8004**, then return to its original shape and dimensions when the loading is removed. If desired, the clearance **8032** could be filled with a polymer or elastomeric material to tailor the deflection properties of the joint member **8002** and provide damping between the insert **8006** and the cup **8004**.

FIG. **71** depicts a joint member **8002'** having a cup **8004'** and insert **8006'**. These two components are of identical construction to the cup **8004** and insert **8006**, respectively, except for the configuration of the contact interface therebetween. Specifically, the step **8014'** of the cup **8004'** is angled rather than L-shaped in cross section. The lip **8030'** of the insert **8006'** has a surface with an angle matching the step **8014'**.

The features described above (that is, the indexing feature, the retention feature, or the resilient spacer) may be incorporated individually into a prosthetic joint member, or they may be applied to a joint member in any combination. For example, FIGS. **72** and **73** depict a prosthetic joint member **9002** similar in construction and function to the prosthetic joint member **2002** described above and having both indexing and retention features. The prosthetic joint member **9002** includes a cup **9004** and an insert **9006**. The cup **9004** includes first indexing features **9014** and the insert **9006** includes second indexing features **9032**. The cup **9002** also includes a retention groove **9012** and the insert **9006** includes retention tabs **9030**. As another example, FIG. **74** depicts a prosthetic joint member **10002** similar in construction and function to the prosthetic joint member **7002** described above and having both resilient spacers and an indexing feature. The prosthetic joint member **10002** includes a cup **10004** and an insert **10006**. The cup **10004** includes first indexing features **10014** and the insert **10006** includes second indexing features **10032**. The cup **10012** also includes spacer grooves **10012** that receive resilient spacer rings **10030**. It is also noted that, the flange of the joint members described above need not be circular, elliptical, or another symmetrical shape in plan view, and need not lie in a single plane. Plan view shapes such as oval, elliptical, and shapes formed from one or more splines is possible. One or more of the flanges may include an open perimeter. Furthermore, the sizing of the flanges and the contact rims relative to the expected loads applied thereto and considering fatigue considerations may be determined as described above for the similar flanges of the prosthetic joint **1000**.

As noted above, known coatings such as titanium nitride, chrome plating, carbon thin films, and/or diamond-like carbon coatings may be used to impart wear resistance or augment the wear resistance of any of the contact surfaces and/or contact rims described above. To the same end, it may be desirable to surface treat either or both interfaces of any of the above-described implants or joints with a laser, shot peen, burnishing, or water shock process, to impart residual compressive stresses and reduce wear. The benefit could be as much from surface annealing and microstructure and microfracture elimination as smoothing itself.

The foregoing has described prosthetic joints with wear-resistant properties and conformal geometries. While specific embodiments of the present invention have been described, it will be apparent to those skilled in the art that various modifications thereto can be made without departing from the spirit and scope of the invention. Accordingly, the foregoing description of the preferred embodiment of the invention and the best mode for practicing the invention are provided for the purpose of illustration only and not for the purpose of limitation.

What is claimed is:

1. A prosthetic joint member comprising:

a concave cup with an outer surface that is bone-implantable, the cup including a first indexing feature;

a concave insert disposed inside the cup, the insert comprising a rigid material and including a concave interior defining a nominal surface, the interior including a cantilevered flange defined by an undercut in the rigid material, the flange defining a wear-resistant first contact surface which protrudes inward relative to the nominal surface and into the concave interior, the insert including a second indexing feature; and

wherein the first and second indexing features engage each other so as to retain the insert in a fixed angular orientation relative to the cup.

2. The prosthetic joint member of claim **1** wherein the flange is asymmetric relative to a balanced centroidal axis.

3. The prosthetic joint member of claim **1** wherein the first indexing feature comprises a ring of notches or grooves.

4. The prosthetic joint member of claim **3** wherein the second indexing feature comprises one or more ribs complementary to the notches or grooves.

5. The prosthetic joint member of claim **1**, wherein:

the cup includes a first retention feature;

the insert includes a second retention feature; and

the first and second retention features engage each other to secure the cup and insert together.

6. The prosthetic joint member of claim **5**, wherein the first retention feature is a groove and the second retention feature is a tab.

7. The prosthetic joint member of claim **6** wherein the tab and groove have cooperating shapes formed such that, after initial engagement of the tab with the groove, additional movement of the insert towards the cup will cause the tab to spring outward while remaining engaged with the groove.

8. The prosthetic joint member of claim **5**, wherein the first and second retention feature comprise complementary detent elements.

9. The prosthetic joint member of claim **1** where the insert is resiliently suspended relative to the cup.

10. The prosthetic joint member of claim **1** wherein a compliant nonmetallic spacer is disposed between the cup and the insert.

11. The prosthetic joint member of claim **1** wherein the cup includes a step and the insert includes a lip which bears against the step, such that a clearance is present between the cup and the insert.

12. The prosthetic joint member of claim **1** wherein at least one elastically-deflectable spacer ring is disposed between the cup and the insert.

13. The prosthetic joint member of claim **12** wherein the spacer ring is received in a groove in the cup.

14. A prosthetic joint including the joint member of claim **1** and a convex member comprising a rigid material with a wear-resistant, convex contact surface received in the insert, where the first contact surface bears directly against the convex contact surface of the convex member, so as to transfer axial and lateral loads between the joint member and the convex member, while allowing pivoting motion between the joint member and the convex member.

15. The prosthetic joint of claim **14**, where the contact surfaces are ceramic, metallic, or a combination thereof.

16. The prosthetic joint of claim **14**, where the flange is sized so as to permit elastic deflection of the flange while limiting stresses in the flange to less than the endurance limit of the material, when a predetermined external load is applied to the joint.

17. The prosthetic joint member of claim **1** wherein the flange has a plan view shape which is noncircular.

18. The prosthetic joint member of claim **1** wherein the flange has an open perimeter.

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